USE OF MICRO UNMANNED AERIAL VEHICLES IN TRANSPORTATION INFRASTRUCTURE CONDITION SURVEYS

A Thesis

by

WILLIAM SCOTT HART

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Nasir Gharaibeh
Committee Members,	Ivan Damnjanovic
	Timothy Lomax
Head of Department,	John Niedzwecki

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ABSTRACT

Use of Micro Unmanned Aerial Vehicles in Transportation Infrastructure Condition Surveys.

(December 2010)

William Scott Hart, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Nasir Gharaibeh

This thesis provides an assessment of the effectiveness of micro unmanned aerial vehicles (MUAVs) as a tool for collecting condition data for transportation infrastructure based on multiple field experiments. The primary experiment entails performing a level of service (LOS) condition assessment on multiple roadside sample units at various locations across the state of Texas. A secondary field experiment entails performing a pavement condition index (PCI) survey on airfield pavements. The condition of these sample units were assessed twice: onsite (i.e., ground truth) and by observing digital images (still and video) collected via a MUAV. The results of these surveys are then analyzed to determine if there are statistically significant differences in the standard deviation and mean values of the condition ratings. This study shows that in favorable site conditions, the MUAV demonstrates promise for improving current roadway inspection methods. However, limitations of the MUAVs field performance show that there is need for improvement in this technology before it can be implemented.

DEDICATION

I would like to dedicate this work to my wife who showed me patience and support throughout my entire educational career. She gave me a reason to keep working and trying to succeed in all that I do.

ACKNOWLEDGEMENTS

I would like to thank Dr. Nasir Gharaibeh for his contribution to the paper and his guidance throughout this entire study. He gave me the opportunity to attend graduate school and to conduct this study.

I would like to thank the Southwest Region University Transportation Center for funding and supporting this project. Their involvement made it possible for this study to take place as well as gave me the opportunity to advance my education.

Arif Chowdhurry played a large role in obtaining the results for this project. He was in charge of most of the onsite inspection surveys and was the key rater at the Riverside test location. His help and cooperation made the findings from this study possible.

I would like to thank my committee members, Dr. Ivan Damnjanovic and Dr. Timothy Lomax, for their guidance and recommendations for this study.

Finally I would like to thank my family for all of their support throughout this entire research process. More than thanks go especially to my wife, who played the most important role of encouraging me during the research of this project.

NOMENCLATURE

ASTM	American Standard for Testing Materials
GPS	Global Positioning System
HMA	Hot Mix Asphalt
LOS	Level of Service
MUAV	Micro-Unmanned Aerial Vehicle
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
SS	Sample Unit Score
UAV	Unmanned Aerial Vehicle

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1. INTRODUCTION

The collection of condition data is a key component of infrastructure asset management systems and maintenance quality assurance programs. The collected data feeds into the decision making processes supported by these management systems. However, data collection can be time consuming, labor intensive, and lack adequate digital visual recording of condition information.

Transportation agencies are continuously seeking to improve data collection methods and technologies. However, most of these efforts have focused on roadway pavements. For example, vehicle-mounted video devices are able to capture the exact profile of the pavement surface that can then be analyzed via computer software, which then output a quantitative value for the condition of that pavement surface (Tsao et al. 1994). Other classes of transportation infrastructure assets (e.g., roadside assets) have received much less attention.

Micro-unmanned Aerial Vehicles (MUAVs) outfitted with digital imaging systems and GPS technology have the potential to improve the efficiency and safety of conducting transportation infrastructure inventory and condition surveys. The MUAV can capture digital video and still-frame images of infrastructure assets, which can then be analyzed in the office in a safe, less stressful work environment, and stored digitally for later use.

This thesis follows the style of *Infrastructure Systems Journal*.

These MUAV systems are commercially available and have been used in areas such as crime scene investigation, cinematography, building inspection, and wind turbine inspection. The main question that this study seeks to answer is how effective are MUAVs in conducting condition surveys for transportation infrastructure? Ultimately, it is hoped that with the adaption of MUAV technology, the data collection process for transportation infrastructure will become safer, more accurate, and more cost-effective, and will provide visual digital records of these assets.

This study will focuses on transportation infrastructure classes where the MUAV technology is most promising and practical to use. Specifically, the study focuses on condition assessment surveys for roadside assets and airfield pavements. Both roadside areas and airfields are difficult to access and pose safety hazard for manual inspections.

Roadside areas are located between the edge of the roadway pavement and the right-of-way boundary line. This also includes the median located between divided multi-lane highways. Figure 1.1 shows the area that is considered to be a ‘roadside’ (excluding the actual pavement surface). Roadside assets and maintenance activities are diverse and have direct impact the safety of the travelling public and the proper use of the agency’s resources. Example roadside assets and maintenance activities include culvert and storm drain maintenance, side ditch maintenance, barrier and guardrail maintenance, vegetation management, and litter pickup.

Airfield pavements are located in runways, taxiways, and aprons. These pavements are regularly inspected not only to monitor their structural and materials integrity, but also to guard against foreign object damage (FOD) to airplanes. FOD can be caused by debris from pavement cracks and joints.

Figure 1.1. Roadside Area (Google Images)

1.1 Research Objectives

The main goal of this project is to enhance the data collection methods for transportation infrastructure condition and inventory through the use of MUAV technology. This entails the following specific objectives:

- Evaluate the effectiveness of using MUAVs for roadside condition assessment.
- Evaluate the effectiveness of using MUAVs for airfield pavement condition assessment.

The above objectives will be accomplished through a series of field experiments. The roadside field experiments entail performing a level of service (LOS) condition assessment surveys on several sample units at three different roadways in Texas (IH-20 near Tyler, IH-35 near Dallas, and local streets in the Riverside Campus of Texas A&M University). The airfield pavement experiment entails performing a Pavement Condition Index (PCI) survey on several sample units at the Riverside Airfield. In each experiment, the condition of each sample unit is assessed twice: onsite (i.e., ground truth) and on images captured by the MUAV. The results of these experiments are compared and analyzed statistically to reveal possible inferences about the MUAV as a data collection technology for transportation infrastructure.

1.2 Thesis Organization

This thesis report is organized into six sections, as follows:

- Section 1 presents the motivation for conducting this study and defines the research objectives and scope.
- Section 2 provides a review of the relevant literature.
- Section 3 describes the methods and materials used in the primary field experiments (i.e., roadside experiments).
- Section 4 discusses the results of the roadside field experiments.
- Section 5 discusses the methods and results of the secondary field experiments (i.e., airfield pavement experiment).
- Section 6 presents the conclusions and recommendations of this study.

2. LITERATURE REVIEW

2.1 Roadway Condition Assessment Methods for Maintenance Quality Assurance

Most existing roadway maintenance quality assurance (MQA) programs use a form of the infrastructure condition assessment method that was originally developed in 1985 by Florida DOT and then refined under NCHRP Project 14-12 (Highway Maintenance Quality Assurance) (Stivers et al. 1999). This method allows maintenance contractors and agencies to periodically measure how well maintenance forces are achieving certain performance standards and LOS targets. It also allows for benchmarking of current LOS and for measuring increase or decline in LOS over time.

The MQA process entails periodic field inspections of the conditions of various roadway assets and maintenance activities. Each maintainable roadway asset (e.g., drainage structures) and feature (e.g., roadside grass and trees) present within randomly selected roadway sample units is inspected periodically to determine if it meets condition/performance standards established by the agency. The sample units are typically 0.1-0.2 mile long. The inspection process can utilize a Pass/Fail assessment method (commonly referred to as attribute-based assessment), or it can incorporate a 1-5 rating scale (commonly referred to as variable-based assessment) to describe the roadway conditions. Tennessee DOT's maintenance rating form (which uses pass/fail ratings) and TxMAP's rating form (e.g., which uses 1-5 rating scales, with 5 representing ideal conditions) are shown in Figures 1.2 and 1.3, respectively, as examples.

MAINTENANCE RATING FORM

Region: 3 District: 33 Segment ID: 276

Inspector:		County:	HOUSTON
		Route:	SR049
		Special Case:	0
System Type:	State Route	County Seq.:	1
Inspection Period:	7/2006	Begin LM:	2.5
Date of Inspection:		End LM:	2.6

Maintenance Element		Pass	N/A	Fail
TRAVELED PAVEMENT				
ASPHALT	ASHP CRACKING			
	ASPH POTHOLES			
	ASPH ALLIGATOR CRACKING			
	ASPH FLUSH/HEAVE/RAVEL			
	ASPH EDGE DROPOFF			
RUTTING	MAINLINE RUTTING			
	INTERSECTION RUTTING			
CONCRETE	CONC JOINTS			
	CONC CRACKING			
	CONC POTHOLES			
	CONC EDGE DROPOFF			
	CONC SLAB FAULTING			
SHOULDER				
SH. ASPHALT	ASPH SHLD CRACKING			
	ASPH SHLD/ROADWAY JOINT			
	ASPH SHLD POTHOLES			
	ASPH SHLD ALIGATORCRACK			
	ASPH SHLD FLUSH/HEAVE			
	ASPH SHLD EDGEDROPOFF			
	ASPH SHLD BUILDUPS			
SH. CONCRETE	CONC SHLD JOINTS			
	CONC SHLD CRACKING			
	CONC SHLD POTHOLES			
	CONC SHLD EDGEDROPOFF			
	CONC SHLD SLAB FAULTING			
SH. UNPAVED	UNPVD SHLD EDGEDROPOFF			
	UNPAVED SHLD BUILDUPS			
	UNPAVED SHLD WASHOUTS			
	CURB + GUTTER			

Maintenance Element	Pass	N/A	Fail
ROADSIDE			
GRASS			
LANDSCAPING + WILDFLOWERS			
LITTER			
FENCE			
SWEEPING			
GRAFFITI			
VEGETATION + BRUSH			
SLOPES/EROSION/TURF RUT			
DRAINAGE			
BOX CULVERTS			
CROSSDRAIN PIPES			
DITCHES			
CATCH BASINS + INLETS			
SIDE DRAINS			
TRAFFIC SERVICES			
WARNING/REGULATORY SIGNS			
ADVISORY SIGNS			
PAVEMENT MARKINGS			
RAISED PAVEMENT MARKERS			
GUARDRAIL/G.R. TERMINALS			
BARRIER WALLS			
ATTENUATORS			

Figure 2.1. Example Pass/Fail Condition Rating Method (Tennessee DOT Maintenance Rating Method).

Texas Maintenance Condition Assessment Inspection Form			
District / Maintenance Section	/	Assessment No.	
County		Inspection No.	
Highway		Inspection Reference Marker:	
Inspector		Date	
Accompanied by		Time	
Surface Type	__ JCP __ Hot Mix __ Seal __ CRCP __ Plant Mix __Micro Mixed Surface_________________________		

Component Element	Performance Standard (Average)	Rating	COMMENTS
Pavement			
Main Lane - Rutting	Do not count failures. Do not rate concrete.		
Main Lane – Cracking	Do not rate failures.		
Main Lane – Failures	No failures, Patches <1/4" high or low.		
Main Lane – Ride	Ride smooth with no settlement.		
Edges	1 ft. On and 1 ft. Off Pavement.		
Shoulders	_____Concrete, two feet or over.		
Traffic Operations			
Raised Pavement Markers	Always rate.		
Signs – Large	Installed on I or H beams or sign Bridge.		
Signs – Small	Chevrons are small signs.		
Striping, Pavement Graphics	Required Graphics are present. Score 1 if not striped.		
Attenuators	Rate if present.		
Delineators	Include OM3's.		
Roadside			
Vegetation Management	Do not rate C/G Section. Do not count off if grass has been herbicided.		
Litter	Do not rate in C/G Section.		
Sweeping	Rated as Needed. Turn Lanes, Bridges, along curbs and barriers.		
Trees and Brush	Not rated in C/G Section.		
Drainage	Not rated in C/G Section. Includes high edges.		
Encroachments	Not rated in C/G Section.		
Guard Rails	Stand Up Ends. No approach Rail at Bridges.		
Mail Boxes	Rated as Needed. Includes Paper Boxes.		
General Public Rating	Safety, User Comfort and Aesthetics, Litter, Missing Signs (Route Markers), Ride and Mowing.		
Note: Ratings are based upon the following: Excellent - New or like new, Good - No work needed, Average - Minimal acceptable condition as shown in the performance measures, Poor - Needs work, Fail - In failed condition, needs rehabilitation or reconstruction.			

Figure 2.2. Example 1-5 Scale Condition Rating Method (TxMAP).

Weighting factors can be assigned for asset types and maintenance features based on their level of importance to the highway agency and the traveling public (i.e., the customer). Techniques such as customer surveys and focus groups can be used to obtain input from the travelling public. Wilson Orndoff (2005) has developed customer survey instruments for highway asset valuation based on input from three affected groups (decision makers, businesses, and the general public). The Texas Transportation Institute (TTI) conducted a series of focus groups in 2009 to assess the public's priorities and to investigate issues relating to mobility, connectivity, pavement quality, funding, and general perceptions of the Texas Department of Transportation (TxDOT) operations (Geiselbrecht et al. 2009).

2.2 Pavement Condition Surveys

Major strides have been made in developing and implementing pavement condition surveys. Early efforts involved the use of direct panel ratings, where a panel of raters drives the surveyed pavement and subjectively rate the pavement sections either using a numeric scale or verbal descriptions such as good, fair, poor etc. based on observed distress types and ride quality. One of the pioneering efforts in this area was the American Association of State Highway Officials (AASHO) Road Tests in the 1950s (Carey and Irick 1960). A panel subjectively rated sections of different pavement types in Ottawa, Illinois on a 0-5 scale, known as the Present Serviceability Rating (PSR). Currently, direct panel ratings are used on a limited basis to supplement more objective indices. In the 1970s, researchers began to develop mathematical models that capture the effect of distress type, severity, and extent on the condition score. One commonly used survey is the Pavement Condition Index (PCI) Survey, which was developed in the late 1970s by the U.S. Army Corp of Engineers and is used in this study. More detailed discussion of the PCI condition assessment method is provided in Section 3 of this thesis.

2.3 Data Collection Methods

Automated inventory and condition surveys of pavement assets have come a long way. Vehicle-mounted sensors (digital imaging systems, laser, acoustic, etc.) are able to capture accurate pavement surface condition that can then be analyzed via computer software, which then output a quantitative value for the condition of that pavement asset (Tsao et al. 1994). While advances have been made in developing these technologies for roadway pavement, roadside assets are not as accessible and therefore currently require manual inspection methods. A recent survey of 48 transportation agencies from 40 different states in the U.S. showed that 34 agencies use manual methods for collecting roadside and drainage condition data (Pantelias et al. 2009). The same survey showed that only three agencies use manual methods for collecting roadway pavement condition data. Manual methods for conducting roadside condition and inventory surveys involve certain safety issues, ranging from traffic crashes to natural hazards such as washouts, sharp changes in elevation, or hidden objects (see example shown in Figure 2.1).

Additionally, these manual inspection methods lack an accurate record of the roadside's true condition. Inadequate data records make it virtually impossible to re-evaluate previously inspected roadside sections without having to travel back to the same site.

Figure 2.3. Demonstration of MUAV's Potential for Creating a Safer Work Environment.

The next section will discuss how unmanned aerial technology has progressed over the past years and previous research in using this technology for collecting infrastructure condition and inventory data.

2.4 Evolution of the Micro-Unmanned Aerial Vehicle

The early models of unmanned aerial vehicles or UAVs were simple drones that were remotely operated from an on-ground location. As computer integration became more present in the military, these vehicles evolved to be more autonomous. UAVs were first designed to act as decoys to distract or detour opposing forces from events occurring on the ground. Later UAVs were modified to perform surveillance missions to gather intelligence from locations deemed too dangerous for human personnel. After the Vietnam War, military science agencies set out to find a more "soldier safe" method for reconnaissance (Levinson 2010). This led to the funding of design-based projects to produce a usable aircraft that could be piloted unmanned, but have the same operational functions of a manned aircraft. Since the military began to use this technology more extensively, private companies began designing different size, shape, and configured UAVs to meet their demand. Present day UAVs being used by the armed forces are fully autonomous that can perform multiple tasks, such as seek and destroy, pre-determined flight, and supply and reinforcement (Taylor 2004).

UAVs are much like manned aerial vehicles in size and weight. This causes a problem for situations in which mobility is critical. The recent transformation of the U.S. armed forces to un-man the "front lines" has created a demand for smaller UAVs that can be carried and operated by a single person. Each branch of the armed services has adopted its own version of the UAV, which suits its individual needs. However, since these UAVs are much smaller in size, they have been given the name micro-unmanned aerial vehicle, or MUAV. The modern MUAV plays a more logistic role in the military that was not predicted in its early development (Taylor 2004). MUAVs are taking the place of manned aircraft in dangerous forward missions that range from resupplying forward soldiers, providing air support, tactical combat missions, and true to its design, reconnaissance. The shift to MUAVs has opened many doors for civilian applications, including infrastructure condition assessment, to take advantage of this state-of-the-art technology.

2.5 Current Uses of Micro-Unmanned Aerial Vehicles

This section provides an overview of various applications of MUAVs as a data collection technology.

The military has many applications for MUAVs. In its earliest existence, MUAVs were simply used as targets and decoys that would distract and detour any opposing forces. As video technology progressed, these MUAVs were then outfitted with media devices that could produce visual images for military decision makers. As design improved, MUAVs were able to carry larger payloads, which expanded their versatility and use. Video imaging combined with computer and GPS technologies led to the adaptation of the present day omniscient MUAV. Private military contractors are performing additional research and development projects to advance this relatively new technology. It is envisioned that military strategist will be able to send an MUAV into an occupied area and real-time information of movement of opposing forces as well as size of opposing forces can be revealed. The captured digital images can be streamed live to military decision makers. Military officers also use MUAVs to enhance strategic awareness of the battlefield. This is a visual inspection and inventory process in which the MUAV collects images of all allied assets on the ground in order to plan for future advancements and delegate missions (Levinson 2010). Private military contractors also produce MUAVs for civilian applications.

Like most military technologies, the commercial sector has found applications in which MUAVs can be used. MUAVs are currently being used in applications such as firefighting, law enforcement, and private surveillance. MUAVs are also used by fire departments to monitor expansion of fires so that instant preventative action can be taken using the real-time video taken by the MUAV. Law enforcement agencies are using MUAVs to track and follow vehicle pursuits. Traditionally, law enforcement personnel follow a fleeing SSpect creating a dangerous situation for both the law officers as well as the public influenced by the chase. MUAVs allow law officers to safely follow a fleeing SSpect covertly until he/she stops, at which time he/she can be apprehended. Large land development companies are beginning to use recreational class MUAVs to assess progress and procurement of their investments. Video inventory of each stage of a project can be recorded and stored for future use (Newcome 2004).

More associated to this study, MUAVs are being used in different infrastructure asset management applications. The transportation sector has begun to explore the feasibility of using UAV systems in infrastructure management such as bridge condition inspection (Metni and Hamel 2007). Bridge inspection has always been a difficult task, especially assessing the underside of the pavement surface. MUAVs can be piloted to capture images that were before unattainable. Limited research efforts have begun in pavement condition inspection that implements the same type of advanced software as the inspection vans currently being used by many DOT agencies (Herold et al. 2004, Zhang 2008a, Zhang 2008b, Jengo et al. 2005). Research has started where roadway traffic data is collected via MUAVs. The images collected by an MUAV can be later analyzed to monitor the amount of usage a road can observe (Coifman et al. 2006 and Srinivasan and Latchman 2004). Rathinam et al. (2008) developed a detection algorithm that enables UAVs to identify and localize linear infrastructures such as canals, roads, and pipelines. This same technology could one day be applied to the application this study is proposing.

The next section will describe different types of MUAVs that are available for commercial use.

2.6 Types of MUAVs

MUAVs can be classified into two main types: plane-configured and helicopter-configured MUAVs. These classifications are used in this study so that their operation can easily be visualized. .

A plane-configured MUAV (see examples shown in Figures 2.4 and 2.5) mimics that of a traditional single propeller driven aircraft. These MUAVs have the ability to fly a straight-line path and must be designed to obey the same laws of aero-dynamics that apply to traditional aircraft. The wingspan on this type of MUAV can vary from twelve inches up to four feet, varying on application. Since the plane type of MUAV must be in motion to take flight and to land, durability problems arise if not properly operated.

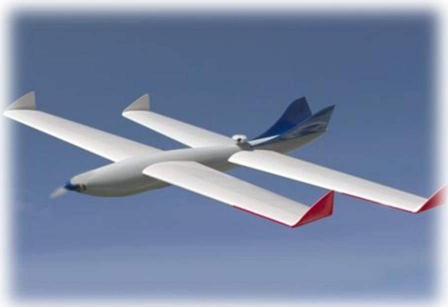

Figure 2.4. Dragan Fly Innovations Tango Plane Type MUAV (Dragan Fly 2010).

Figure 2.5. NightHawk MUAV Plane Type MUAV (ARA 2010).

One advantage of plane-configured MUAV is that greater speeds can be achieved than that of other types of MUAVs. This MUAV type can also carry larger payloads since wingspan can SStain forward motion and lift under heavier loads. Another advantage of this type of MUAV is its flight time. Since the MUAV can utilize a gliding affect while in flight, fuel or battery power can be conserved. This MUAV also have some disadvantages that limit its capabilities and application. Since the MUAV must maintain forward motion, limited angle and amount of images can be captured. This MUAV type cannot be deployed in confined spaces, as it requires room to take flight and gain operational speed. For locations along busy highways this is not the most appropriate condition. As previously mentioned, this MUAV must be in motion to take off and land and thus there is potential for the vehicle to be damaged during this process. This is the cause of the majority of failures for application of this type of MAUV (Newcome 2004).

A helicopter-configured MUAV (see examples shown in Figures 2.6 and 2.7) utilizes upward thrust induced by a single or multiple propellers to maneuver in flight. This MUAV type does not need to maintain constant forward motion in order to stay airborne, and thus it has higher degree of freedom for movement. This design allows the MUAV to be much more compact. The typical size for helicopter-configured MUAV is approximately 2-3 ft diametrically. However, recent research has used nanotechnology to produce an insect-sized helicopter-configured MUAV (Newcome 2004). This technology is still limited to espionage and close quarter reconnaissance.

Figure 2.6. Telerobotics Helicopter MUAV (Telerobotics, 2009).

Figure 2.7. Dragan Fly X6 Helicopter MUAV (Dragan Fly, 2010).

Helicopter-configured MUAVs have many advantages over other types of MUAVs. One such advantage is that it can loiter in place. This is very beneficial when coupled with GPS technology. With this capability, predetermined coordinates can be stored in the navigational controls of the MUAV, which allows for taking digital images at pre-defined locations. Another advantage of this MUAV type is its maneuvering capabilities. Its propeller design allows it to make radical changes in direction as well as change in elevation. Another advantage of this MUAV type is its takeoff and landing capabilities. The hovering capabilities allow this MUAV to takeoff from a standing position, which makes it ideal for operation in restricted space. This MUAV also comes with its own set of disadvantages that are not present in other types. One example is that its design does not allow it to carry large payloads, which can become a problem with trying to outfit the MAUV with multiple technologies. Another disadvantage of the Helicopter style MUAV is its fuel/battery capacity. Since the design of the MUAV requires more power to maintain flight, fuel/battery consumption is higher than (and thus its flight time is lower than) plane-configured MUAVs.

In summary, the advantages of plane-configured over helicopter-configured MUAVs include:

1. greater speed
2. ability to carry larger payloads, and
3. ability to glide while in flight (which reduces fuel or battery consumption).

Advantages of helicopter-configured over plane-configured MUAVs include:

1. greater maneuverability (which allows for making immediate and sharp changes in flight direction),
2. ability to loiter in place (which, when coupled with GPS, allows for programming the MUAV to hover at predetermined coordinates)
3. smaller size, and
4. ability to takeoff from a standing position.

3. PRIMARY FIELD EXPERIMENTS

The primary field experiments entailed performing a level-of-service (LOS) condition assessment on 10 roadway sample units on IH-20 in Tyler, Texas, 2 roadway sample units on IH-35 in Denton, Texas, 5 roadway sample units at Riverside Campus. Each of the roadway sample units is approximately 0.1 miles long. The condition of each sample unit was assessed twice:

a. Onsite (i.e., ground truth): Three inspectors rated the roadside assets and maintenance activities within each sample unit directly in the field, and

b. MUAV video: A fourth inspector rated the same sample units by observing digital images (still and video) collected via the MUAV.

The inspectors had similar training in conducting roadside condition surveys. The main components of these field experiments are discussed in the following sections. This includes the LOS condition assessment method, the MUAV model used to collect data, and the statistical tests used to analyze the data.

3.1 Roadside Condition Assessment Method

A roadside condition assessment method that is being developed for the Texas Department of Transportation (TxDOT) was used in these field experiments. This method is the result of TxDOT Research Project 0-6387. Performance standards for key roadside asset types and maintenance activities were developed based a survey of TxDOT's 25 districts (Shelton 2010). These asset types and maintenance activities include elements such as mowing of roadside grass, upkeep of landscaped areas, upkeep of trees, shrub, and vines, maintenance of ditches and front slopes, maintenance of culverts, cross-drain pipes, and drain inlets, maintenance of chain link fences, guard rails, cable median barrier, and attenuators, and cleanliness of the section (e.g. litter, debris and graffiti cleanup).

The condition assessment field surveys are based on random sampling. Random sampling is used to ensure realistic and affordable data collection requirements. In a random sampling scheme, once the rating zones (e.g., a 10-mile highway segment) are established, sample units of equal length (typically 0.1-mi long) are chosen from within these zones using random sampling techniques. This condition assessment method consists of the following steps: (Shelton 2010):

1) The highway maintenance project is divided into N sample units (each 0.1-mi long)
2) n sample units are selected randomly for field survey

3) The randomly selected sample units are inspected and rated on a "Pass/Fail/Not Applicable" basis using the performance standards shown in Figure 3.1 (a total of 57 performance standards for 11 roadside asset types and maintenance activities). The inspection form used for the visual inspection is shown in Figure 3.1.

4) A 0-100 sample score (SS) is computed as a weighted average score for all elements within the sample unit, as follows:

$$SS = \frac{\sum_{i=1}^{k} \frac{PS_i}{AS_i} \times w_i}{\sum_{i=1}^{k} 100 \times w_i} \qquad \text{Eq. 1}$$

where *PS* is the number of passing performance standards; *AS* is the number of applicable performance standards; *w* is an agency-specified priority multiplier (or weight) for each roadside element, and *k* is the total number of roadside elements within the sample unit. A set of priority multipliers were developed based on feedback from TxDOT's districts and are shown in Table 3.1.

5) A roadside $\overline{LOS}$ for the highway maintenance project is computed, as follows

$$\overline{LOS} = \frac{\sum_{j=1}^{n} SS_j}{n} \qquad \text{Eq. 2}$$

where SS_j is the sample score for sample unit *j* and *n* is the total number of inspected sample units (i.e., sample size).

6) Because the LOS is computed based on a random sample, it is recommended that a confidence interval (CI_{LOS}) be computed for the LOS, as follows:

$$CI_{LOS} = \overline{LOS} \pm z_{\alpha/2} \times \frac{s}{\sqrt{n}} \qquad \text{Eq. 3}$$

where s is the standard deviation of SS; z is the z-statistic for a desired confidence level (e.g., $z_{0.025} = 1.96$ for 95% confidence).

A sample calculation for one sample unit is shown in Figure 3.2. The inspection results are used to assess the roadside's performance, set maintenance priorities, and make funding allocation decisions.

Inspector's Name:			**Inspection Date:**	
District:	**Highway:**	**Milepoint:**	**Sample Unit No.:**	**Urban/Rural:**

Roadside Element	No.	Performance Standard	Grade (Pass, Fall, NA)
Mowing and Roadside Grass	1	Obtained TxDOT approval of herbicides	
	2	Paved areas (shoulders, medians, islands and edge of pavement) are free of grass	
	3	Unpaved areas (shoulders, slopes, and ditch lines) are free of bare or weedy areas	
	4	Roadside vegetation in the mowing area is at least 85% free of noxious weeds (undesired vegetation)	
	5	Roadside grass height (rural areas): 7-30 inches	
	6	Roadside grass height (urban areas): 7-24 inches	
Landscaped Areas	7	Obtained TxDOT approval of herbicides	
	8	90% of landscaped areas is free of weeds and dead or dying plants	
	9	Grass height: 12 inches maximum.	
Trees, shrubs and Vines	10	No trees and/or vegetation that obscure the message of a roadway sign	
	11	No dead trees and no leaning trees that present a hazard	
	12	Vertical clearance over sidewalks and bike paths is at least 10 ft	
	13	Vertical clearance over roadway and shoulder is at least of 18 ft	
	14	Clear horizontal distance behind guardrail is at least 5 ft for trees	
Ditches and Front Slopes	15	There are no eroded areas, washouts, or sediment buildup that adversely affects the flow of water in the ditch	
	16	No erosion that will endanger the stability of the front slope, creating an unsafe recovery area.	
	17	No washouts or ruts greater than 3-in deep and 2-ft wide, in front slope	
	18	90% of the ditch structure (90% of the length and 90% of the depth) functions as intended	
	19	No joint separation, misalignment, or undermining in concrete ditches	
	20	No deviations (hills, holes, etc.) greater than 6 inches in depth or height, in front slope	
Culvert and Cross-Drain Pipes	21	At least 75% of the cross sectional area of each pipe is free of obstructions and functions as intended with no evidence of flooding	
	22	The grates are of the correct type and size, unbroken, and in place	
	23	No water infiltration causing pavement failures, shoulder failures, or roadway settlement.	
	24	No cracking, joint failures, or erosion of culverts and cross-drain pipes	
Drain Inlets	25	The grates are of the correct size and are unbroken. Manhole lids are properly fastened.	
	26	No hazard from exposed steel or any deformation of the inlet	
	27	No erosion, settlement, or sediment around boxes	
	28	Outlets are not damaged and are functioning properly	
	29	85% of the opening area is not obstructed.	
	30	No surface damage 0.5 sq.ft or more.	
Chain Link Fence	31	No open gates	
	32	No opening in the fence fabric greater than 1.0 sq.ft	
	33	No opening in the fence fabric with a dimension greater than 1.0 ft	
Guard Rails	34	No missing posts, offset blocks, panels or connection hardware	
	35	No damaged end sections	
	36	No penetrations in the rail	
	37	No panel lapped incorrectly	
	38	No more than 10% of the guardrail offset blocks in any continuous section are twisted.	
	39	Contractor to address guardrail deficiencies (listed above) within 3 days	
	40	No 25 continuous feet that is 3 inches above or 1 inch below the specified elevation	
	41	No more than 10% of the wooden posts or blocks in any continuous section are rotten or deteriorated	
Cable Median Barrier	42	No missing or damaged posts, cables, and connections	
	43	Damaged end sections	
	44	No loose cable, incorrect weave or installation	
Attenuators	45	Each device functions as intended	
	46	No visually-observed malfunctions, such as water or sand containers that are split, compression of the device, misalignment, etc.	
	47	No missing parts	
	48	Contractor to address attenuator deficiencies (listed above) within 3 days	
Litter and Debris	49	No litter that creates a hazard to motorist, bicyclist, or pedestrian traffic is allowed	
	50	Less than 50 pieces of fist size or larger litter/debris within 0.1 miles	
	51	The volume of litter does not exceed 3 cubic feet per acre of right-of-way	
	52	In Urban areas, remove dead animals from the right of way within 24 hours	
	53	In rural areas, remove large dead animals from the traffic lanes within 24 hours	
Graffiti	54	No damaged surface or coating due to graffiti removal	
	55	Obscene, sexually or racially explicit or "gang-related" graffiti shall be removed within 3 days	
	56	Restore the surface to an appearance similar to adjoining surfaces	
	57	Non-obscene graffiti shall be removed within two weeks of discovery	

Figure 3.1. Roadside Inspection Form Used in Field Experiment.

Table 3.1. Roadside Priority Multipliers Used in Field Experiment.

Roadside Element	Priority Multipliers (1-4 scale)
Mowing and Roadside Grass	2.8
Landscaped Areas	1.6
Trees, shrubs, and vines	2.1
Ditches and Front Slopes	2.7
Culvert and Cross-Drain Pipes	2.9
Drain Inlets	2.9
Chain Linked Fence	1.7
Guard Rails	3.3
Cable Median Barrier	3.5
Attenuators	3.7
Litter and Debris	1.7
Graffiti	1.6

Element	Total No. of Standards	No. of Applicable Standards	No. of Passing Standards	Element Importance Rating	Element Score (0-100)
Mowing and Roadside Grass	6	4	3	2.8	75.0
Landscaped Areas	3	2	1	1.6	50.0
Trees, shrubs and Vines	5	5	5	2.1	100.0
Ditches and Front Slopes	6	4	3	2.7	75.0
Culvert and Cross-Drain Pipes	4	3	2	2.9	66.7
Drain Inlets	6	NA	NA	2.9	
Chain Link Fence	3	NA	NA	1.7	
Guard Rails	8	NA	NA	3.3	
Cable Median Barrier	4	NA	NA	3.5	
Attenuators	4	NA	NA	3.7	
Litter and Debris	5	4	4	1.7	100.0
Graffiti	4	NA	NA	1.6	

0-4 importance rating determined based on a survey of TxDOT's maintenance engineers

Weighted Sum (WS)	1065.8
Maximum Weighted Sum (MWS)	1380.0
Sample Unit Score = WS/MWS =	**77.2%**

Figure 3.2. Sample Condition Rating Calculation.

3.2 MUAV Used in the Field Experiments

As discussed earlier, the purpose of this experiment is to assess the effectiveness of MUAVs as a data collection method for roadside assets. Since roadside assets are not always clear along the entire length of a sample unit (e.g., trees and debris can block the flight path), this study required an MUAV that can manipulate its flight path and that can maneuver in tight spaces. The selected MUAV must also be able to utilize GPS technology so that its flight path can be tracked and recorded for later use. With the known GPS coordinates of a sample unit, unique and complete databases can be created for inventory purposes. The MUAV must be able to capture high-resolution video and images for later analysis and editing. The characteristics of the MUAV needed in this study can be illustrated as follows:

- Compact and simple design.
- Loiter capabilities (still motion capabilities).
- Ability to takeoff/land in confined spaces.
- Carry state-of-the-art imaging devices.
- Equipped with GPS capabilities.
- Equipped with onboard and satellite media storage devices.
- Durable.
- Capable of maintaining constant flight for longer than 10 minutes.
- Reasonably priced.
- Easily piloted/operated.

- Applicable for other potential areas of research.

Several companies were considered in the MUAV selection process for this study. Most MUAVs were not candidates solely based on price. The selected MUAV model was the Dragan Fly X6 helicopter-configured MUAV. This model is produced by Dragan Fly Innovations, a company located in Saskatoon, Canada. Table 3.2 shows the helicopter's and imaging system's specifications in detail.

Table 3.2. Dragan Fly X6 Helicopter Technical Specifications (Summarized) Provided by Dragan Fly Innovations, Manufacturer.

Helicopter Size (Fully Assembled)	
Width	36 in.
Length	33 in.
Height	10 in.
Weight And Payload	
Helicopter Weight	2.2 lbs.
Payload Capacity	1.1 lbs.
Maximum Gross Takeoff Weight	3.3 lbs.
Flight Characteristics	
Unassisted Visual Reference Required	Path Entered Flight Capabilites
Max Climb Rate	23 ft/s
Max Descent Rate	13 ft/s
Max Turn Rate	90 °/s
Approximate Max Speed	30 mph
Minimum Speed	None
Launch Type	Vertical Take Off and Landing
Maximum Altitude	8,000 ft.
Max Flight Time	25 min.
Camera Type	
Still Camera	10 MP Digital Still
Motion Camera	720p High-Definition
Max Storage	2 GB
GPS	
Satellites Used	16
Position Update Rate	4 Hz
GPS Capabilities	Position Hold, Location Data

Figure 3.3 below shows a picture of the Dragan Fly X6 and labels some of its unique design features.

Figure 3.3 Dragan Fly Innovations X6 Helicopter MUAV.

Figure 3.4 shows the actual MUAV that was purchased and used for this study being piloted at the Riverside Campus to demonstrate some of its basic capabilities.

The X6 is being used by many different universities for research purposes. For example, MIT is currently using the X6 to create an advanced search and rescue system, which utilizes multiple camera configurations to locate missing persons after an accident or catastrophic event (Coppinger 2006). Vanderbilt University is the using the X6 to test computerized autonomous flight programs for military use (PRWeb 2007). Large industrial companies such as NEC, Alstrom and WSE technologies have chosen the Dragan Fly X6 to perform visual inspections of their facilities (Dragan Fly 2010).

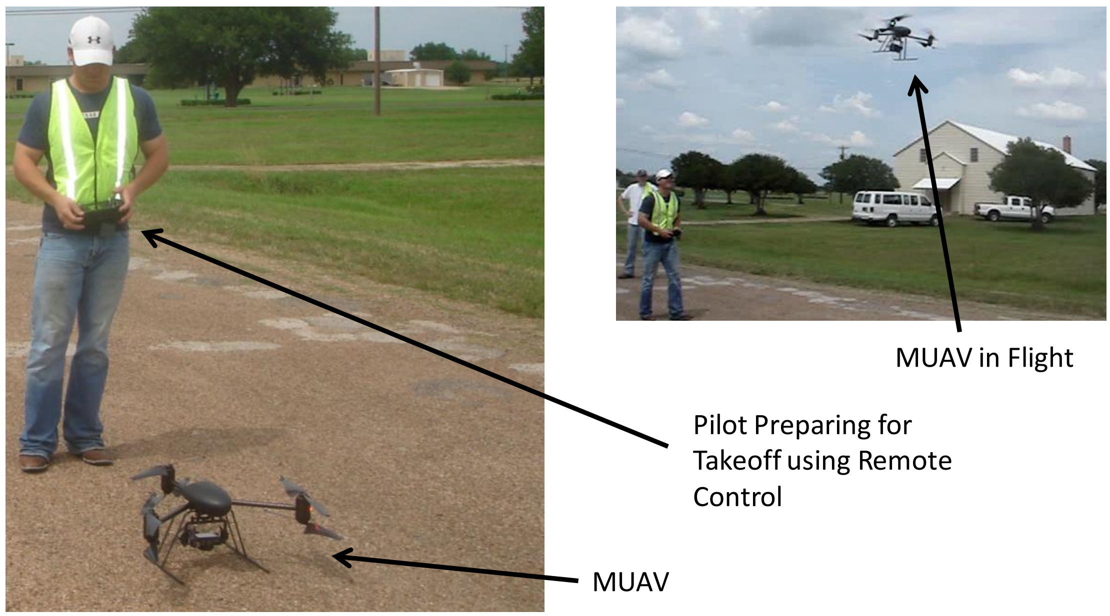

Figure 3.4. MUAV Used in Field Experiment.

3.3 Statistical Analysis of Experiment Results

Once all of the data is collected for each experiment location, the statistical tests were conducted to determine if there are statistically-significant differences in the standard deviation and mean values of the condition ratings obtained from the two different survey methods.

There were two statistical tests that were used in this analysis. The first statistical test is the Students paired t-test. The null hypothesis for this test is that the sample means of the two datasets are statistically equal. The t-test used for this study was a two-tailed test where the resulting p-value is examined to test the null hypothesis. A 95% confidence level was used in the inference made about the null hypothesis. This comparison of the sample means of the two datasets will reveal statistical differences between the onsite ratings and the MUAV-captured ratings.

The second statistical test used in this study is the F-test. The null hypothesis for this test is that the variances between two sets of paired datasets are statistically equal. The p-value for this test is examined to test for the rejection of the null hypothesis. The test applies a 95% confidence level to the inference made about the null hypothesis.

4. DISCUSSION OF RESULTS

The results of the primary field experiments are discussed in this section, on an experiment-by-experiment basis. The raw inspection data is provided in Appendix B through D.

4.1 Tyler IH-20 Level of Service Results

The collected survey data for the Tyler IH-20 experiment location is summarized in Table 4.1. Equation 1 was used to calculate the SS for each sample unit. The first two columns in the table reference the sample unit numbers used in this analysis to the sample unit numbers used in the onsite inspection.

Table 4.1. SS Ratings for Tyler IH-20 Experiment Location.

Sample Unit No.	Onsite Sample No.	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
1	7	63	75	58	100
2	18	87	83	82	73
3	23	84	83	94	87
4	28	100	83	93	80
5	32	93	100	94	67
6	33	96	94	93	82
7	40	83	94	83	67
8	48	88	88	82	79
9	57	100	92	92	100
10	60	88	81	91	100

Figure 4.1 shows the level of agreement between the performance standards ratings (Pass, Fail, or Not Applicable) obtained by monitoring MUAV videos and corresponding ratings obtained directly in the field by three different inspectors. Considering all performance standards, 72-95 percent of the time, the ratings assigned by the MUAV video rater matched those assigned by the field raters. On average, these ratings matched 81% of the time.

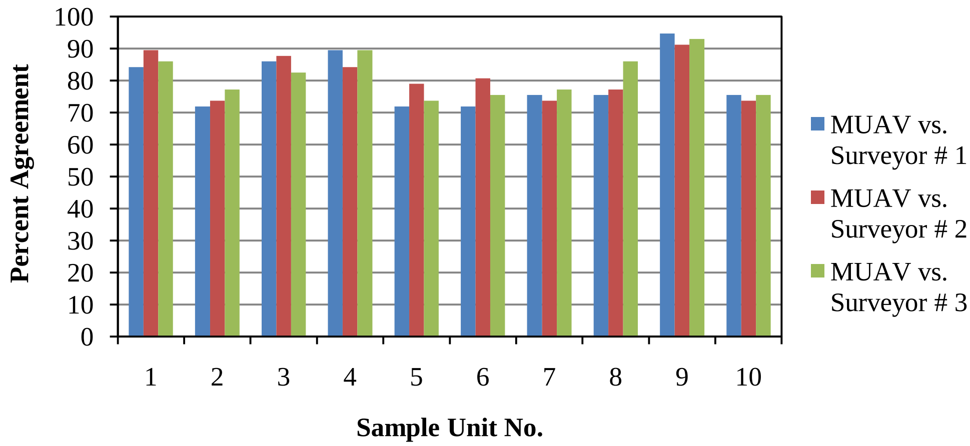

Figure 4.1. Percent Agreement between MUAV and Onsite Ratings (Pass/Fail/Not Applicable) for Tyler Experiment.

Figure 4.2 shows the sample unit scores computed using ratings obtained from the onsite (field) raters and the corresponding scores computed using ratings obtained from the MUAV.

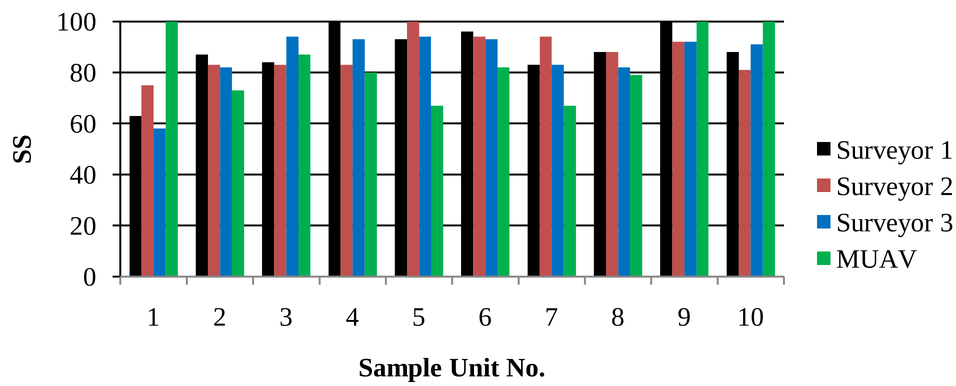

Figure 4.2. Onsite vs. MUAV-based Sample Scores for Tyler.

Figure 4.3 shows each of the sample unit scores categorized by surveyor. This figure helps reveal any patterns or tendencies between each of the four different surveyors and how they score roadside condition surveys. The figure reveals that, with the exception of sample units 1, 9, and 10, the scores given by the MUAV inspection are consistently lower than the other three onsite surveyors. This can be attributed to the false readings in sample units 1, 9, and 10, where certain failed assets could not be detected by the MUAV.

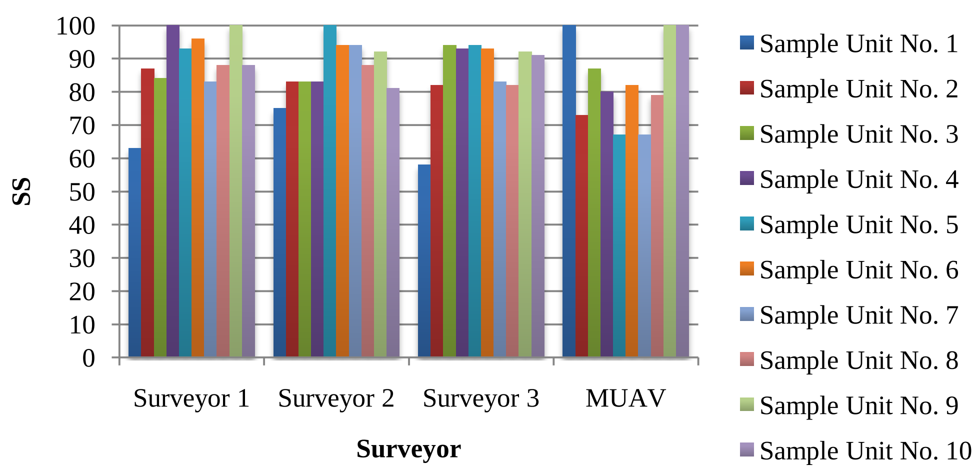

Figure 4.3. Sample Scores vs. Surveyor for Tyler.

As discussed earlier, two statistical tests were conducted on the SS results. The first was a two-tailed t-test, in which the onsite SS data sets were compared to the corresponding MUAV SS data set, under the null hypothesis that true mean values are equal. The second statistical test was the F-test, which was conducted on the same data sets under the null hypothesis that the variances are equal. Table 4.2 shows the results of these two statistical tests. The results show that, at a 95% confidence level, there is no statistical evidence that the null hypothesis in either case is false.

Table 4.2. Statistical Results Comparing Onsite vs. MUAV-based Sample Scores (95% Confidence Level) for Tyler.

Comparison	Sample Size (number of sample units)	T-Test p-value	F-Test p-value	Evidence of Difference in SSs (Reject Null Hypothesis?)
Surveyor # 1 vs. MUAV	10	0.390	0.585	t-Test: No F-Test: No
Surveyor # 2 vs. MUAV	10	0.437	0.126	t-Test: No F-Test: No
Surveyor # 3 vs. MUAV	10	0.437	0.650	t-Test: No F-Test: No

4.2 Dallas IH-35 Level of Service Results

This experiment was conducted to evaluate the performance of MUAV in adverse weather and field conditions. The roadway has a heavy traffic volume (average daily traffic (ADT) of 124,000 vehicle per day), with a large percentage of truck traffic (60-65%). The wind speed during the experiment was 15 to 20 mile per hour. Several attempts were made to fly the MUAV; however, the MUAV was unstable to fly in these adverse conditions. The experiment was stopped after collecting data from two sample units. The collected survey data for these two sample units is summarized in Table 4.3. Equation 1 was used to calculate the SS for each sample unit. The first two columns in the table reference the sample unit numbers used in this analysis to the sample unit numbers used in the onsite inspection.

Table 4.3. SS Results for Dallas IH-35 Experiment Location.

Sample Unit No.	Onsite Sample No.	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
1	5	79	81	76	100
2	38	70	67	50	100

Figure 4.4 shows the level of agreement between the performance standards ratings (Pass, Fail, or Not Applicable) obtained by monitoring MUAV videos and corresponding ratings obtained directly in the field by three different inspectors. Considering all performance standards, 65-84 percent of the time, the ratings assigned by the MUAV video rater matched those assigned by the field raters. On average, these ratings matched 76% of the time. No statistical tests were conducted due to the small sample size.

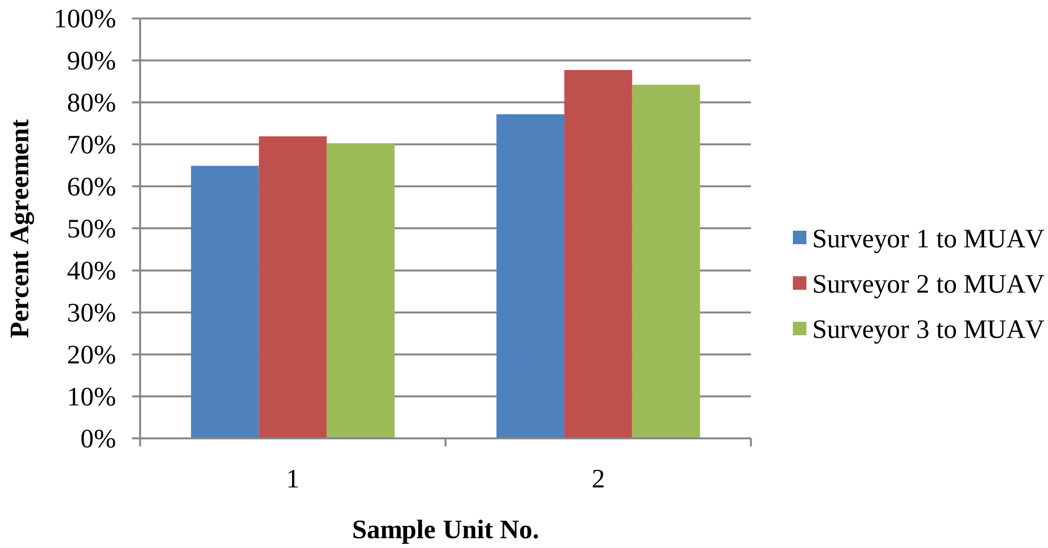

Figure 4.4. Percent Agreement between MUAV and Onsite Ratings (Pass/Fail/Not Applicable) for Dallas.

Figure 4.5 shows the sample unit scores computed using ratings obtained from the onsite (field) raters and the corresponding scores computed using ratings obtained from the MUAV.

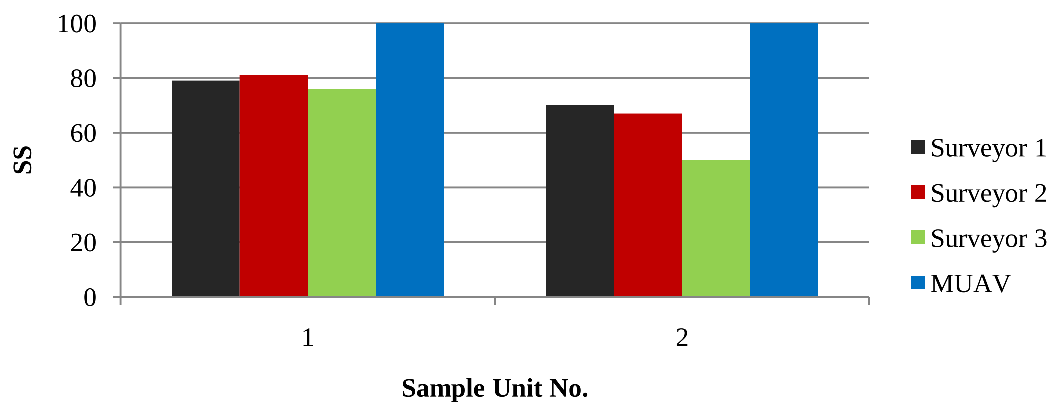

Figure 4.5. Onsite vs. MUAV-based Sample Scores for Dallas IH-35 Experiment.

Figure 4.6 shows the MUAV consistently scored higher than the rest of the surveyors. Again, this can be attributed to the MUAV's poor quality images which failed to detect certain assets that did not meet the performance standards.

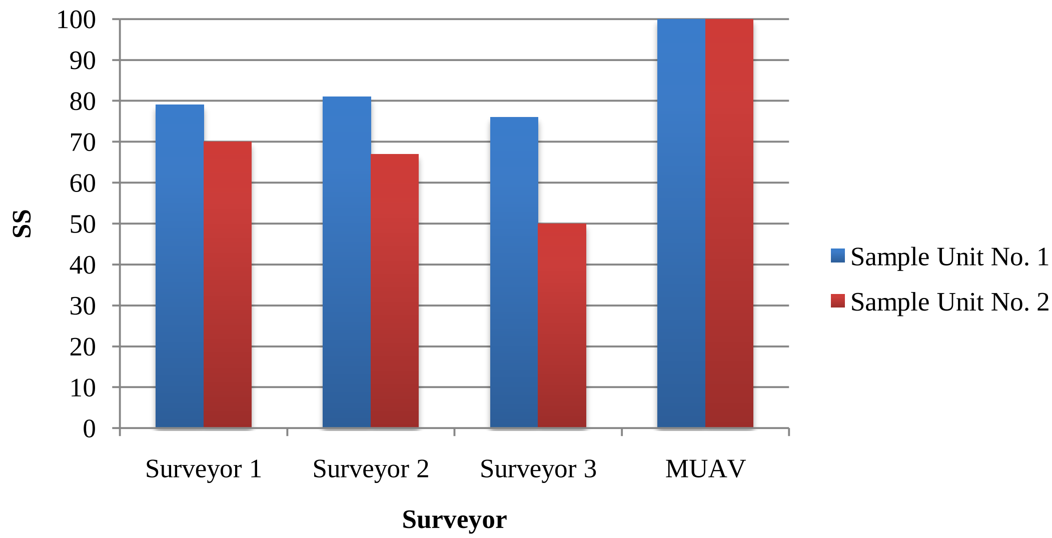

Figure 4.6. Sample Scores vs. Surveyor for Dallas.

4.3 Riverside Level of Service Results

As discussed earlier, the sample units of this experiment are located on local streets at the Riverside campus of Texas A&M University. These streets are 2-way 2-lane with very low traffic volume (ADT of approximatly150 vehicles per day, with percent truck of 10-15%). The collected survey data for the Riverside experiment location is summarized in Table 4.4. Equation 1 was used to calculate the SS for each sample unit.

It should be noted that only one field surveyor was used in this experiment. This is the same Surveyor 1 in the Tyler and Dallas experiments.

Table 4.4. SS Results for Riverside Experiment Location.

Sample Unit No.	Onsite Sample No.	Surveyor 1	MUAV
1	1	96	100
2	2	91	96
3	3	86	92
4	4	83	96
5	5	78	100

Figure 4.7 shows the level of agreement between the performance standards ratings (Pass, Fail, or Not Applicable) obtained by monitoring MUAV videos and corresponding ratings obtained directly in the field by three different inspectors. Considering all performance standards, 75-93 percent of the time, the ratings assigned by the MUAV video rater matched those assigned by the field raters. On average, these ratings matched 86% of the time.

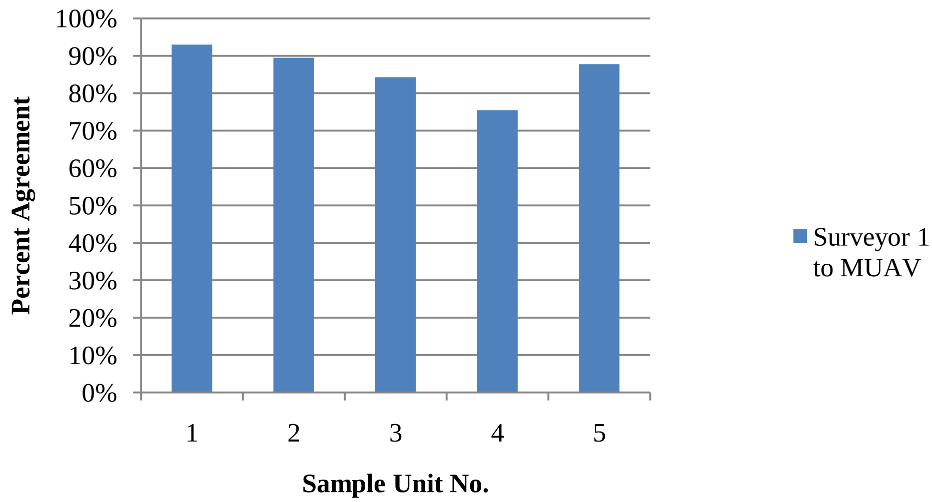

Figure 4.7. Percent Agreement between MUAV and Onsite Ratings (Pass/Fail/Not Applicable) for Riverside.

Figure 4.8 shows the sample unit scores computed using ratings obtained from the onsite (field) raters and the corresponding scores computed using ratings obtained from the MUAV.

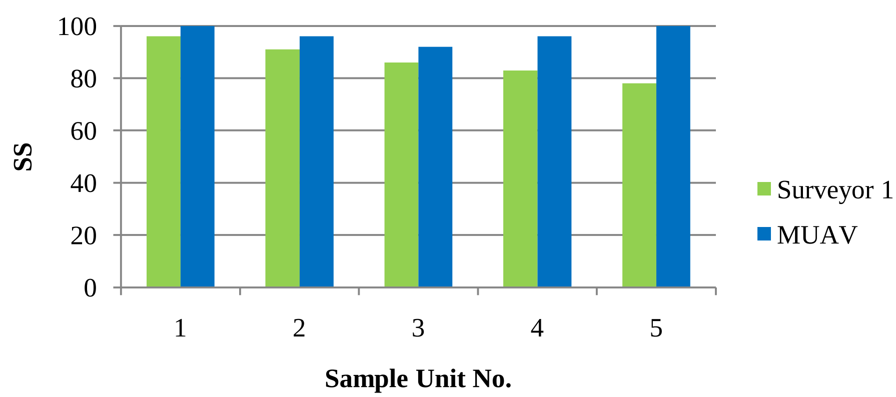

Figure 4.8. Onsite vs. MUAV-based Sample Scores for Riverside Experiment.

Figure 4.9 shows once again that the MUAV scores are consistently higher than the onsite surveyor's ratings. Similar to previous sites, this can be attributed to the false readings where certain failed assets could not be detected by the MUAV.

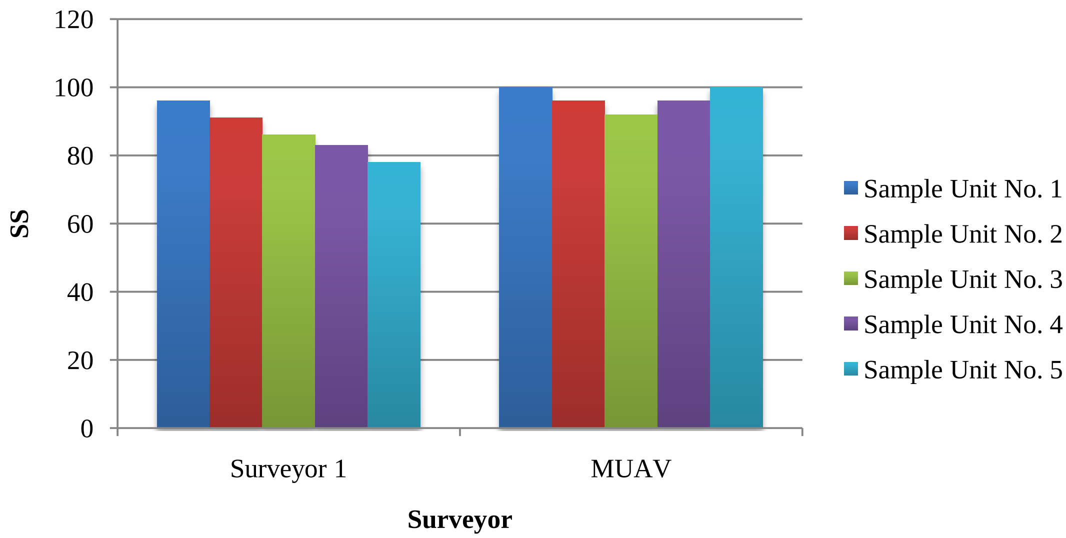

Figure 4.9. Sample Scores vs. Surveyor for Riverside.

4.4 Analysis of False Readings

For this project, a false reading is a case where an asset is rated incorrectly using the MUAV captured data. There are two types of false reading that occurred in this study. The first occurred when an asset in a sample section was observed and rated in the visual inspection, but was missed in the MUAV inspection. The second occurred when the MUAV captured an image of an asset, but could not be properly rated due to lack of visibility or clarity.

The Tyler, TX experiment location provided the most information in regards to these false readings. Each sample unit was more closely analyzed to determine when the onsite survey differed from the MUAV-captured survey by three or more different standards for any given asset class or maintenance activity. For example, a Drain Inlet is one asset class that has six standards to be measured in the roadside condition survey. If three or more of these standards were recorded differently for the two survey methods then it was considered a false reading. The threshold value of three standards was used because differences in one or two standards have very minor effect on the sample score. Table 4.5 shows all of the false readings that were observed at the Tyler, TX experiment location.

Table 4.5. False Readings for Tyler, TX IH-20.

Sample Unit No.	Asset	False Reading	Effect on Score
1	Ditches and Front Slopes	Onsite survey issued a failing score, MUAV captured a passing score.	Increased
2	Ditches and Front Slopes	Onsite survey issued a passing score, MUAV captured a failing score.	Decreased
2	Guard Rail	Onsite survey captured the asset, the MUAV missed the asset.	Decreased
3	Culvert and Cross-Drain Pipes	Onsite survey captured the asset, the MUAV missed the asset.	Decreased
4	Ditches and Front Slopes	Onsite survey issued a passing score, MUAV captured a failing score.	Decreased
5	Ditches and Front Slopes	Onsite survey issued a passing score, MUAV captured a failing score.	Decreased
5	Culvert and Cross-Drain Pipes	Surveyor 1 rated the asset, the MUAV failed to capture it.	Decreased
6	Ditches and Front Slopes	Onsite survey issued a passing score, MUAV captured a failing score.	Decreased
6	Drain Inlet	Onsite survey captured the asset, the MUAV missed the asset.	Decreased
7	Guard Rail	Onsite survey captured the asset, the MUAV missed the asset.	Decreased
7	Ditches and Front Slopes	Onsite survey issued a passing score, MUAV captured a failing score.	Decreased
8	Ditches and Front Slopes	Onsite survey issued a passing score, MUAV captured a failing score.	Decreased
10	Culvert and Cross-Drain Pipes	Onsite survey captured the asset, the MUAV missed the asset.	Increased
10	Drain Inlet	Onsite survey captured the asset, the MUAV missed the asset.	Increased

Out of the 10 sample units that were surveyed, there were 14 total false readings that affected the outcome of the MUAV rating process. 50% of these false readings occurred when rating ditches and front slopes. The remaining 50% of the false readings occurred when the MUAV failed to capture a specific asset due to lack of visibility, clarity or maneuverability. To show exactly what happened during the rating process to cause the false reading, each of the 14 readings are shown in Appendix D side by side with a brief explanation of each case. Figures 4.10 and 4.11 show an example false MUAV reading. In this example, the last image in the video that the MUAV captured for Sample Unit No. 2. The image taken onsite shows that the guardrail is included in the sample unit (See Table A.1 for section reference). The MUAV was not able to capture the image of the guardrail due to tree and signage preventing maneuverability coupled with uncontrollable winds. Since the MUAV missed the guardrail (which met all performance standards), the other standards that received a failing rating carried impact on the overall condition of the sample unit, lowering the SS rating for the MUAV rating. It is worth noting that the images shown in this analysis were taken using the same HD digital camera. The wind jostles the MUAV around, which resulted in poor quality images. The quality of the images decreases as the wind speed increases.

Figure 4.10. Sample Unit No. 2 MUAV Captured Image: Failed to Capture Guard Rail.

Figure 4.11. Sample Unit No. 2 Onsite Conditions: Guard Rail That Was Inspected.

4.5 Operational Performance of MUAV

The operational performance of the MUAV was observed in the field under three conditions: time of day, wind speed, and flight speed. These observations are summarized in the following paragraphs.

The MUAV was flown at three different times throughout the day in order to find the optimum window to collect best quality images. The lighting condition is not truly a test of the MAUV's capabilities, but rather the camera mounted on the MUAV. The specific digital camera that was used in this study was a LUMIX DMC-LX3 manufactured by Panasonic. The camera captured 720p high-definition video images and 10.2 megapixel still images. It was observed that the most optimum time of day to capture images was between 8:00 A.M. until 12 noon. In the afternoon, there is excessive glare off of adjacent pavement surfaces, which reduced the quality of the captured images.

Weather was the most restricting parameter in the entire data collection process. While the MUAV was not flown in rainy weather, wind was found to be the most restricting weather condition. Generally, the MUAV performed well and was easy to control in 0-5 mile per hour winds. In 5-10 mile per hour winds, the MUAV became more difficult to control, but with some training, data could be collected. Wind speed greater than 10 miles per hour interfered in operating the MUAV and resulted in "shaky" video that was difficult to analyze. The MUAV was not operational (could not be controlled) in 15-

mile per hour (or more) winds.

Flight speed affects the quality of video and images that the MUAV captures as well as endurance of the MUAV (i.e. maximum flight time). The slower the MUAV travels, the higher the quality of data becomes. However, slower flight speed (i.e., longer flight times per sample unit) reduces the number of sample units surveyed per battery. Approximately, 1.5 minutes of flight time per 0.1 mile sample unit (allowing 4 sample units to be collected per battery), appears to be most practical.

5. SECONDARY FIELD EXPERIMENT

The secondary field experiment entailed performing a pavement condition survey on 15 airfield pavement sample units at the Riverside Airfield. Each sample unit consists of two by ten concrete pavement slabs (each slab is 15-ft long and 12.5-ft wide). The raw inspection data for this experiment along with the Pavement Condition Index (PCI) computations are provided in Appendix F.

Similar to the roadside LOS experiment, the PCI was assessed for each pavement sample unit twice:

c. Onsite (i.e., ground truth): One inspector performed the PCI survey directly in the field, and

d. MUAV video: A second inspector performed the PCI survey by observing digital images (still and video) collected via the MUAV.

The results of these surveys are analyzed to determine if there are statistically-significant differences in the standard deviation and mean values of the PCI values obtained through the above two surveys.

5.1 Pavement Condition Index Methodology

The PCI method was developed and standardized by the U.S. Army Corps of Engineers in 1978 to measure the quality of airfield pavements for military applications. The PCI inspection method was later adopted by the American Standard for Testing Materials (ASTM). The most current method is designated as ASTM D5340-10 (Standard Practice for Airfield Condition Index Surveys) is used in this field experiment. The PCI is a 0-100 (with 100 representing the perfect condition) numerical indicator that rates the condition of the pavement based on the distress observed on the surface of the pavement. This index provides some indication of the structural and materials integrity and functional condition.

The general expression for computing PCI is as follows (Shahin et al. 1978, Shahin et al. 1980):

$$PCI = C - \sum_{i=1}^{P} \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij}) F(t, q) \qquad \text{Eq. 4}$$

where C is the maximum value of the condition index (i.e., perfect score of 100), is the deduct value function that varies with distress type (T), severity (S), and density (D). $a(T,S,D)$ functions are usually polynomial for concrete pavement and "multiple discrete" natural logarithmic for asphalt pavement. $F(t,q)$ is an adjustment function that varies with total deduct value (t) and number of deducts (q). i and j are counters for distress types and severity levels, respectively. p is the total number of observed distress types. m_i is the number of severity levels for the ith distress type. Typically, three levels of severity are used (low, medium, and high). ASTM D5340-10 contains standard charts of the $a(T,S,D)$ deduct value functions and the $F(t,q)$ adjustment function.

The PCI method uses random sampling, where a network of pavement structures is divided into branches, sections, and sample units. Sample units are randomly selected from each section and then aggregated to assess the condition of the entire network. The number of sample units to be inspected is determined based on total number of sample units per section, the pavement type (e.g. HMA or PCC), and the desired confidence level. Typically, the sample unit size is 5000 square feet for HMA pavement, or 20 PCC slabs for concrete pavement.

The computed PCI value is then related to a verbal description of the pavement condition using a standard scale that ranges from “Excellent” to “Failed.”

A more detailed description of the PCI inspection and rating procedure can be found in sections 10 through 12 of ASTM 5340-10.

5.2 Riverside PCI Results

The PCI values for the inspected sample units at the Riverside Airport experiment location are shown in Figure 5.1 for the onsite survey as well as the MUAV survey. It can be seen that the PCI values of the onsite survey are consistently higher than those of the MUAV survey. This pattern is due to consistent false joint spalling readings by the MUAV. Figure 5.2 shows an example of this type of false distress reading by the MUAV. The MUAV-generated image incorrectly shows what looks like medium-severity joint spalling, but when inspected by the onsite rater, this distress was found to be low-severity and sporadic. A close up of the joint shown in Figure 5.3 can be found in Figure 5.3 that shows the joint to only contain low severity joint spalling. The MUAV image mischaracterizes the discoloration of PCC slab at the joint as joint spalling.

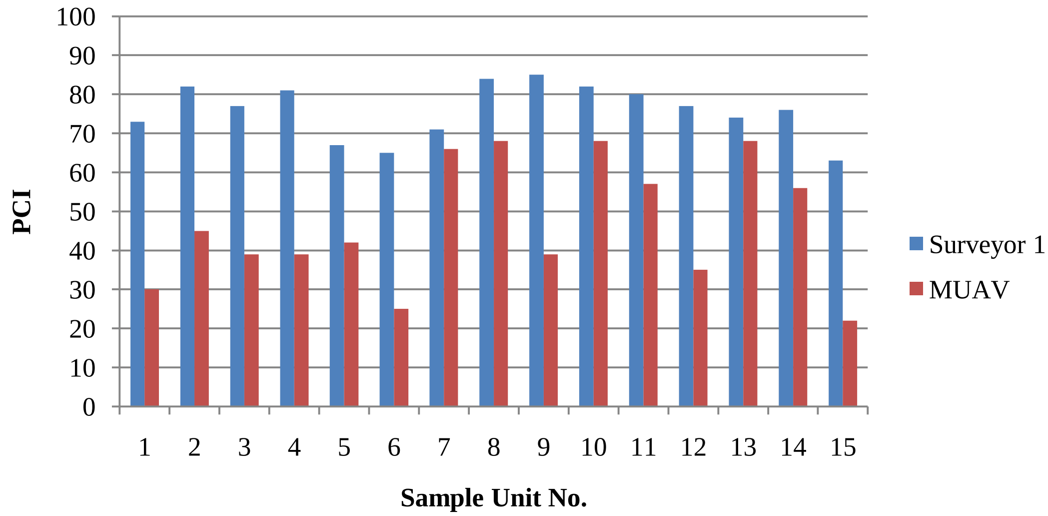

Figure 5.1. Onsite vs. MUAV-based PCI Values for Riverside Airport Pavement.

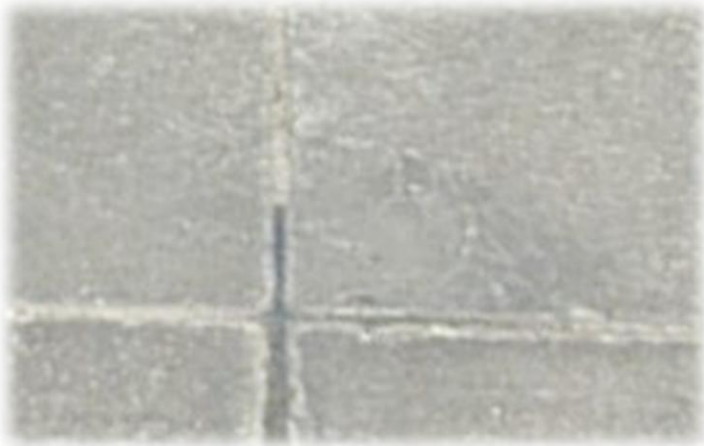

Figure 5.2. Example of False Reading of Joint Spalling by MUAV (Image Captured by MUAV).

Figure 5.3. Onsite Conditions for Riverside Airfield Pavement, Low Severity Cracking.

Table 5.1 contains the statistical analysis results for the comparison between PCI scores based on onsite survey data and MUAV data. These results show that, at a 95% confidence level, there is statistical evidence to reject the null hypothesis in both cases (i.e., the two data sets are different in terms of both mean and variance).

Table 5.1. Statistical Results Comparing Onsite vs. MUAV-based Sample Unit PCI Scores (95% Confidence Level) for Riverside Airport.

Comparison	Sample Size (number of sample units)	T-Test p-value	F-Test p-value	Evidence of Difference in SSs (Reject Null Hypothesis?)
Surveyor # 1 vs. MUAV	15	0.0000	0.0032	t-Test: Yes F-Test: Yes

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

This study provides an assessment of the effectiveness of MUAVs as a tool for collecting condition and inventory data for transportation infrastructure based on field experiments. The motivation of this study is to improve the safety, accuracy, and time efficiency of infrastructure condition assessment surveys, and to identify technologies that can provide visual digital records of these surveys.

This study focuses on transportation infrastructure classes where the MUAV technology is most promising and practical to use. Specifically, the study focuses on condition assessment surveys for roadside assets and airfield pavements. The primary field experiments entailed performing a level of service (LOS) condition assessment on 10 roadside sample units on IH-20 in Tyler, Texas, 2 roadway sample units on IH-35 in Denton, Texas (Dallas Area), 5 roadway sample units located within Riverside Campus. The secondary field experiment entailed performing a pavement condition index (PCI) survey on 15 airfield pavement sample units at the Riverside Airfield at Texas A&M University. The condition of these sample units was assessed twice: onsite (i.e., ground truth) and by observing digital images (still and video) collected via the MUAV. Figure 6.1 provides a summary assessment of the capabilities of the MUAV based on lessons learned from this study.

	Good	Adequate	Poor
Mowing and Roadside Grass		√	
Landscaped Area	√		
Trees, Shrubs, and Vines	√		
Dithces and Front Slopes			√
Culverts and Cross Drain Pipes			√
Drain Inlets			√
Chain Link Fence	√		
Guard Rails		√	
Cable Median Barrier	√		
Attenuators	√		
Litter and Debris	√		
Graffiti	√		

Figure 6.1. Capabilities of the MUAV Based on Lessons Learned.

6.2 Conclusions

Based on the results of this study, the following conclusions can be made:

- Weather was the most restricting parameter in the data collection process. While the MUAV was not flown in rainy weather, wind was found to be the most influential weather condition. The MUAV was easy to control and produced the highest quality images in 0-5 mile per hour winds. The MUAV was not operational (could not be controlled) in 15 mile per hour (or more) winds.

- For rural highways and local streets and wind speed less than 10 miles per hour, the MUAV produced adequate quality images for estimating the LOS for roadside assets.
- For urban highways and wind speed greater than 10 miles per hour, the MUAV was difficult to operate and produced poor-quality images for estimating the LOS for roadside assets.
- The build-up of grass was the main cause of false MUAV readings; which suggests that MUAV surveys are best conducted shortly after grass mowing.
- For airfield pavements, the MUAV produced poor-quality images for estimating the PCI. The main cause of false MUAV readings was the mischaracterization of the discoloration of PCC slab at the joint as joint spalling.
- In favorable site conditions (low traffic volume and low wind speed), the MUAV survey was faster and safer than manual surveys.
- MUAV inspection, in most cases, produces higher condition ratings for roadway surveys than onsite inspections.

Overall, the field experiments described in this paper show that the MUAV is a promising technology for improving current data collection methods for transportation infrastructure condition assessment. However, false readings and limitations on the operational performance of MUAVs show that there is still a need for improving this technology before it can be adopted in the field. Currently, the MUAV may be best used for screening infrastructure condition before detailed field inspections are conducted.

6.3 Recommendations

The following recommendations for further research are offered:

- Investigate the effect of flight altitude on the quality of MUAV images.
- Investigate the use of more powerful cameras that allow for higher resolution images to be magnified without losing clarity.
- Investigate the use of MUAVs in other infrastructure-related areas, such as monitoring progress in construction projects.
- Evaluate the MUAV's GPS and live data feed capabilities.
- Evaluate the cost-effectives of the MUAV.

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APPENDIX A

TYLER, TX IH-20 RAW DATA

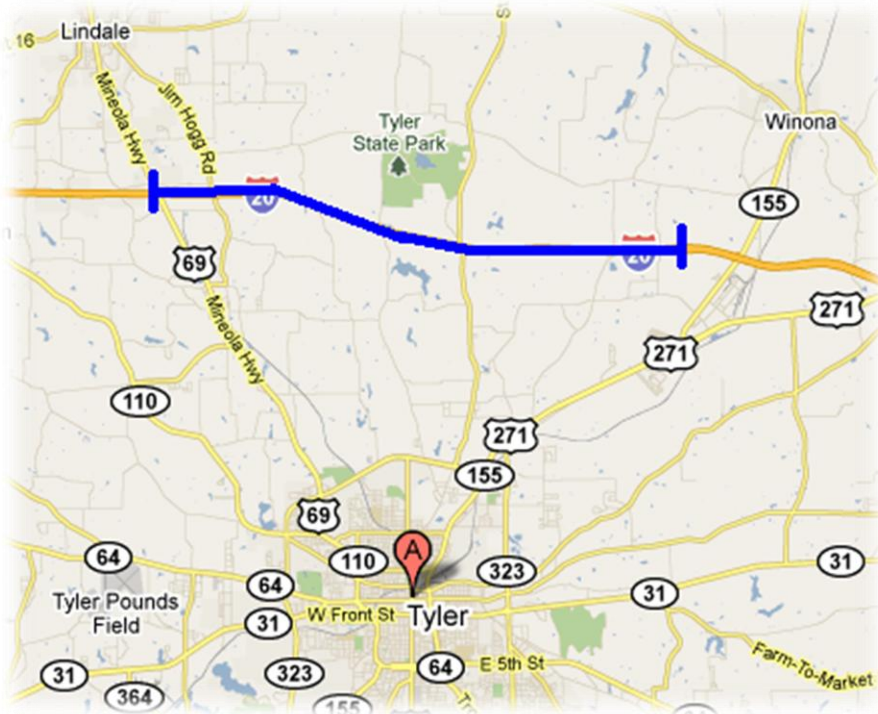

Figure A.1. Tyler, TX IH-20 Experiment Location (Section denoted in Blue).

Table A.1. Tyler IH-20 Reference Table.

Sample Number	Project Sample Unit No.	Start Mile Marker	End Mile Marker	Length (mile)	Urban/ Rural
7	1	556+0.6	556+0.7	0.1	Rural
18	2	557+0.7	557+0.8	0.1	Rural
23	3	558+0.2	558+0.3	0.1	Rural
28	4	558+0.7	558+0.8	0.1	Rural
32	5	559+0.1	559+0.2	0.1	Rural
33	6	559+0.2	559+0.3	0.1	Rural
40	7	559+0.9	560+0.0	0.1	Rural
48	8	560+0.7	560+0.8	0.1	Rural
57	9	561+0.6	561+0.7	0.1	Rural
60	10	561+0.9	562+0.0	0.1	Rural

Table A.2. Tyler IH-20 Sample Unit No. 1 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	P	P	P	P
	F	P	P	P
	F	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	NA	NA	NA	NA
Ditches and Front Slopes	F	P	F	P
	F	F	F	P
	F	P	F	P
	NA	P	P	P
	NA	NA	NA	NA
	F	F	F	P
Culvert and Cross-Drain Pipes	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.3. Tyler IH-20 Sample Unit No. 2 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	F	P	P	P
	P	P	P	F
	F	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	P	NA	NA	NA
Ditches and Front Slopes	P	F	P	P
	P	P	P	F
	P	P	P	F
	NA	P	P	P
	NA	NA	NA	NA
	P	P	P	F
Culvert and Cross-Drain Pipes	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	P	F	F	NA
	P	P	P	NA
	P	P	P	NA
	P	P	P	NA
	F	P	F	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	P	P	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.4. Tyler IH-20 Sample Unit No. 3 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	F	P	P	F
	P	P	P	F
	P	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	NA	NA	NA	NA
Ditches and Front Slopes	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	P	P	P
	NA	NA	NA	NA
	F	F	P	P
Culvert and Cross-Drain Pipes	F	NA	P	NA
	NA	NA	P	NA
	P	NA	P	NA
	P	NA	P	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.5. Tyler IH-20 Sample Unit No. 4 Data.

Roadside Asset Type/ Maintenance	**Surveyor 1**	**Surveyor 2**	**Surveyor 3**	**MUAV**
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	P	P	P	F
	P	P	P	P
	P	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	P	P
	P	NA	P	P
	P	NA	NA	N
	P	NA	NA	P
	NA	NA	NA	NA
Ditches and Front Slopes	P	P	P	P
	P	P	P	F
	P	P	P	F
	NA	P	P	P
	NA	NA	NA	NA
	P	F	P	P
Culvert and Cross-Drain Pipes	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.6. Tyler IH-20 Sample Unit No. 5 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	P	P	P	F
	P	P	P	P
	F	P	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	F
	P	NA	NA	NA
	P	NA	NA	P
	P	NA	NA	P
Ditches and Front Slopes	F	P	P	F
	P	P	P	F
	P	P	P	F
	P	P	P	F
	P	NA	NA	F
	P	P	P	F
Culvert and Cross-Drain Pipes	P	NA	NA	NA
	P	NA	NA	NA
	P	NA	NA	NA
	P	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	P	P	P	P
	NA	P	P	P
	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	P	NA
	NA	NA	NA	P
	P	P	NA	P
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.7. Tyler IH-20 Sample Unit No. 6 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	P	P	P	P
	P	P	P	P
	F	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	P	P
	P	NA	P	P
	P	NA	NA	NA
	P	NA	P	P
	NA	NA	P	P
Ditches and Front Slopes	P	P	P	P
	P	P	P	F
	P	P	P	F
	P	P	P	P
	P	P	F	F
	P	P	P	P
Culvert and Cross-Drain Pipes	P	P	NA	NA
	NA	NA	NA	NA
	P	P	NA	NA
	P	P	NA	NA
Drain Inlets	P	NA	P	NA
	P	NA	P	NA
	P	NA	P	NA
	P	NA	P	NA
	P	NA	P	NA
	P	NA	P	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	P	NA
	NA	NA	P	NA
	NA	NA	P	NA
	NA	NA	P	NA
	NA	NA	P	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.8. Tyler IH-20 Sample Unit No. 7 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	F	P	P	F
	P	P	P	P
	F	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	P	NA	NA	NA
Ditches and Front Slopes	P	P	F	F
	P	P	P	F
	F	P	F	F
	NA	P	P	F
	NA	NA	NA	NA
	F	P	P	P
Culvert and Cross-Drain Pipes	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	P	P	P	NA
	P	P	P	NA
	P	P	P	NA
	P	P	P	NA
	P	P	P	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	P	P	P	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.9. Tyler IH-20 Sample Unit No. 8 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	F
	P	P	P	F
	F	P	P	P
	NA	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	P	NA	NA	NA
	F	NA	NA	NA
Trees, shrubs, and Vines	P	NA	P	P
	P	NA	P	P
	P	NA	NA	NA
	P	NA	P	P
	P	NA	P	P
Ditches and Front Slopes	P	P	F	P
	P	P	P	F
	P	P	F	F
	NA	P	F	P
	NA	NA	NA	F
	P	F	P	P
Culvert and Cross-Drain Pipes	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	P	P	P	P
	P	P	P	P
	P	P	P	P
	P	P	P	P
	F	P	P	P
	NA	NA	NA	NA
	NA	NA	NA	P
	P	NA	P	P
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.10. Tyler IH-20 Sample Unit No. 9 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	P	P	P	P
	P	P	P	P
	P	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	NA	NA	NA	NA
Ditches and Front Slopes	P	P	P	P
	P	P	P	P
	P	P	P	P
	P	P	P	P
	P	P	NA	NA
	P	P	P	P
Culvert and Cross-Drain Pipes	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.11. Tyler IH-20 Sample Unit No. 10 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	P	P	P	P
	P	P	P	P
	F	F	F	P
	NA	NA	NA	NA
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	NA	NA	NA	NA
Ditches and Front Slopes	P	P	P	P
	P	F	P	P
	P	P	P	P
	NA	P	P	P
	NA	NA	NA	NA
	P	F	P	P
Culvert and Cross-Drain Pipes	P	P	P	NA
	P	NA	P	NA
	P	P	P	NA
	F	F	P	NA
Drain Inlets	P	P	P	NA
	P	P	P	NA
	P	P	P	NA
	P	P	P	NA
	F	P	F	NA
	P	P	P	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	P	P	P	P
	P	P	P	P
	NA	NA	NA	NA
	P	NA	NA	NA
Graffiti	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA

Table A.12. Summary Table of Tyler, TX IH-20 SS Ratings

Sample Unit No.	Section	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
1	7	63	75	58	100
2	18	87	83	82	73
3	23	84	83	94	87
4	28	100	83	93	80
5	32	93	100	94	67
6	33	96	94	93	82
7	40	83	94	83	67
8	48	88	88	82	79
9	57	100	92	92	100
10	60	88	81	91	100

APPENDIX B

DENTON, TX IH-35 (DALLAS) RAW DATA

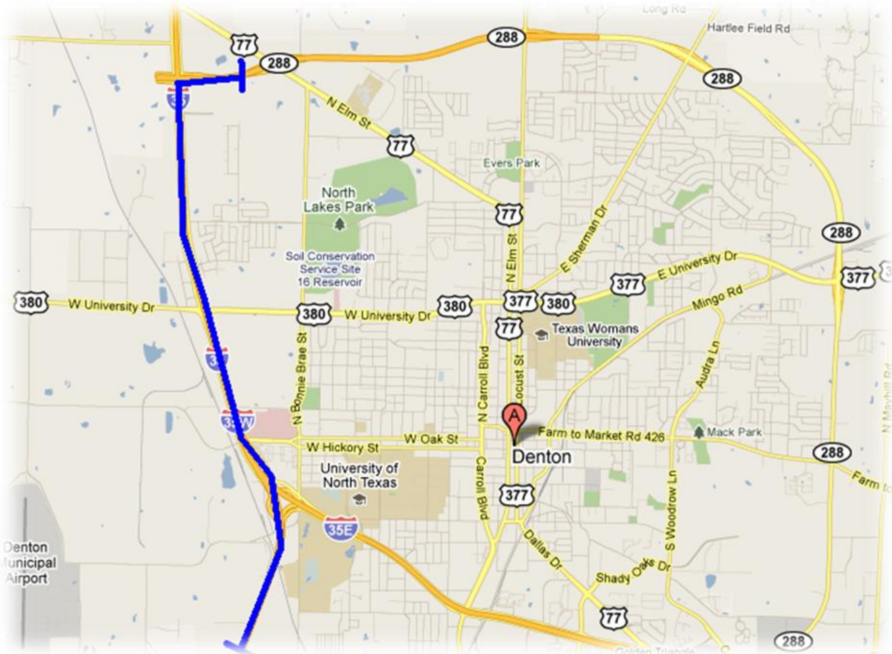

Figure B.1. Denton, TX IH-35 Experiment Location (Section denoted in Blue).

Table B.1. Denton, TX IH-35 Reference Table.

Sample Number	Project Sample Unit No.	Start Mile Marker	End Mile Marker	Length (mile)	Urban/ Rural
5	1	458+0.4	458+0.5	0.1	Urban
38	8	461+0.7	461+0.8	0.1	Urban

Table B.2. Denton, TX IH-20 Sample Unit No. 1 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	NA	P	P	P
	F	P	P	P
	NA	P	P	P
	NA	NA	NA	NA
	F	F	F	P
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	NA	NA	NA	NA
Ditches and Front Slopes	P	P	P	P
	P	P	P	P
	P	F	F	P
	NA	P	P	P
	NA	NA	P	NA
	F	F	F	P
Culvert and Cross-Drain Pipes	NA	P	P	NA
	NA	NA	NA	NA
	NA	P	P	NA
	NA	P	P	NA
Drain Inlets	P	P	P	NA
	P	P	P	NA
	P	P	P	NA
	P	P	NA	NA
	P	P	P	NA
	P	P	P	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	F	F	F	P
	F	P	F	P
	P	NA	NA	NA
	NA	NA	NA	NA
Graffiti	P	NA	NA	NA
	P	NA	NA	NA
	P	NA	NA	NA
	P	NA	NA	NA

Table B.3. Denton, TX IH-20 Sample Unit No. 2 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
Mowing and Roadside Grass	NA	NA	NA	NA
	P	P	P	P
	F	P	P	P
	P	F	P	P
	NA	NA	NA	NA
	F	F	F	P
Landscaped Areas	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Trees, shrubs, and Vines	P	NA	NA	P
	P	NA	NA	P
	P	NA	NA	NA
	P	NA	NA	P
	NA	NA	NA	NA
Ditches and Front Slopes	P	F	F	P
	F	P	F	P
	F	P	F	P
	NA	F	F	P
	NA	NA	NA	NA
	F	P	F	P
Culvert and Cross-Drain Pipes	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Drain Inlets	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Chain Link Fence	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Guard Rails	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Cable Median Barrier	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Attenuators	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
	NA	NA	NA	NA
Litters and Debris	P	P	P	P
	F	P	P	P
	P	P	P	P
	P	NA	NA	NA
	NA	NA	NA	NA
Graffiti	P	NA	NA	NA
	P	NA	NA	NA
	P	NA	NA	NA
	P	NA	NA	NA

Table B.4. Summary Table of Denton, TX IH-35 SS Ratings

Sample Unit No.	Section	Surveyor 1	Surveyor 2	Surveyor 3	MUAV
1	5	79	81	76	100
2	38	70	67	50	100

APPENDIX C

COLLEGE STATION, TX RIVERSIDE CAMPUS DATA

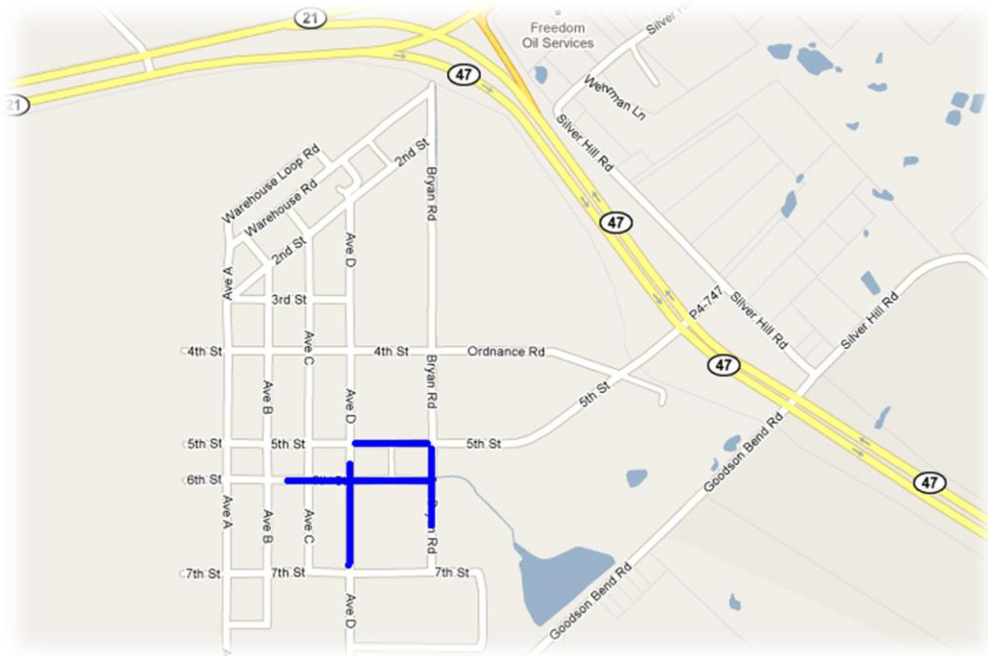

Figure C.1. College Station, TX Riverside Campus Experiment Location (Section denoted in Blue).

Table C.1. College Station, TX Riverside Campus Reference Table.

Project Sample Unit No.	Street	Length (mile)	Urban/ Rural
1	5th Street	0.1	Urban
2	Ave. D	0.1	Urban
3	6th Street	0.1	Urban
4	6th Street	0.1	Urban
5	Bryan Rd.	0.1	Urban

Table C.2. College Station, TX Riverside Campus Sample Unit No. 1 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	MUAV
Mowing and Roadside Grass	NA	NA
	F	P
	P	P
	P	P
	NA	NA
	P	P
Landscaped Areas	NA	NA
	P	P
	P	P
Trees, shrubs, and Vines	P	P
	P	P
	P	NA
	P	P
	NA	NA
Ditches and Front Slopes	P	P
	P	P
	P	P
	NA	P
	NA	NA
	P	P
Culvert and Cross-Drain Pipes	P	P
	NA	P
	P	P
	P	P
Drain Inlets	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Chain Link Fence	NA	NA
	NA	NA
	NA	NA
Guard Rails	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Cable Median Barrier	NA	NA
	NA	NA
	NA	NA
Attenuators	NA	NA
	NA	NA
	NA	NA
	NA	NA
Litters and Debris	P	P
	P	P
	P	P
	P	P
	NA	NA
Graffiti	P	P
	P	P
	P	P
	P	P

Table C.3. College Station, TX Riverside Campus Sample Unit No. 2 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	MUAV
Mowing and Roadside Grass	NA	NA
	F	P
	P	P
	P	P
	NA	NA
	P	P
Landscaped Areas	NA	NA
	NA	P
	NA	P
Trees, shrubs, and Vines	P	P
	P	P
	P	NA
	P	P
	NA	NA
Ditches and Front Slopes	P	P
	P	P
	P	P
	NA	P
	NA	NA
	P	P
Culvert and Cross-Drain Pipes	F	F
	NA	P
	P	P
	P	P
Drain Inlets	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Chain Link Fence	NA	NA
	NA	NA
	NA	NA
Guard Rails	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Cable Median Barrier	NA	NA
	NA	NA
	NA	NA
Attenuators	NA	NA
	NA	NA
	NA	NA
	NA	NA
Litters and Debris	P	P
	P	P
	P	P
	P	P
	NA	NA
Graffiti	P	P
	P	P
	P	P
	P	P

Table C.4. College Station, TX Riverside Campus Sample Unit No. 3 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	MUAV
Mowing and Roadside Grass	NA	NA
	F	P
	P	F
	P	P
	NA	P
	P	NA
Landscaped Areas	NA	NA
	NA	NA
	NA	NA
Trees, shrubs, and Vines	P	P
	P	P
	P	NA
	P	P
	NA	NA
Ditches and Front Slopes	P	P
	P	P
	P	P
	NA	P
	NA	NA
	P	P
Culvert and Cross-Drain Pipes	F	F
	NA	P
	F	P
	NA	P
Drain Inlets	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Chain Link Fence	NA	NA
	NA	NA
	NA	NA
Guard Rails	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Cable Median Barrier	NA	NA
	NA	NA
	NA	NA
Attenuators	NA	NA
	NA	NA
	NA	NA
	NA	NA
Litters and Debris	P	P
	P	P
	P	P
	P	P
	NA	NA
Graffiti	P	P
	P	P
	P	P
	P	P

Table C.5. College Station, TX Riverside Campus Sample Unit No. 4 Data.

Roadside Asset Type/ Maintenance	Surveyor 1	MUAV
Mowing and Roadside Grass	NA	N
	F	P
	P	P
	P	P
	NA	N
	P	P
Landscaped Areas	NA	N
	NA	N
	NA	N
Trees, shrubs, and Vines	P	P
	P	P
	P	N
	P	P
	NA	N
Ditches and Front Slopes	P	P
	P	P
	P	P
	NA	P
	NA	N
	P	P
Culvert and Cross-Drain Pipes	F	F
	NA	P
	F	P
	F	P
Drain Inlets	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Chain Link Fence	NA	NA
	NA	NA
	NA	NA
Guard Rails	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Cable Median Barrier	NA	NA
	NA	NA
	NA	NA
Attenuators	NA	NA
	NA	NA
	NA	NA
	NA	NA
Litters and Debris	P	P
	P	P
	P	P
	P	P
	NA	N
Graffiti	P	P
	P	P
	P	P
	P	P

Table C.6. College Station, TX Riverside Campus Sample Unit No. 5 Data.

Roadside Asset Type/ Maintenance	**Surveyor 1**	**MUAV**
Mowing and Roadside Grass	NA	NA
	F	P
	F	P
	P	P
	NA	NA
	F	P
Landscaped Areas	NA	NA
	NA	NA
	NA	NA
Trees, shrubs, and Vines	P	P
	P	P
	P	P
	P	P
	NA	NA
Ditches and Front Slopes	P	P
	P	P
	P	P
	NA	P
	NA	NA
	F	P
Culvert and Cross-Drain Pipes	P	P
	NA	P
	F	P
	P	P
Drain Inlets	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Chain Link Fence	NA	NA
	NA	NA
	NA	NA
Guard Rails	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
Cable Median Barrier	NA	NA
	NA	NA
	NA	NA
Attenuators	NA	NA
	NA	NA
	NA	NA
	NA	NA
Litters and Debris	P	P
	P	P
	P	P
	P	P
	NA	NA
Graffiti	P	P
	P	P
	P	P
	P	P

Table C.7. Summary Table of College Station, TX Riverside Campus SS Ratings

Sample Unit No.	Section	Surveyor 1	MUAV
1	1	96	100
2	2	91	96
3	3	86	92
4	4	83	96
5	5	78	100

APPENDIX D

MUAV FALSE READINGS AT THE TYLER, TX SITE

Figure D.1. Sample Unit No. 1 MUAV Captured Image: Ditch and Front Slope Passed Inspection.

Figure D.2. Sample Unit No. 1 Onsite Conditions: Ditch and Front Slope Failed Inspection.

Figure D.3. Sample Unit No. 2 MUAV Captured Image: Ditch and Front Slope Failed Inspection.

Figure D.4. Sample Unit No. 2 Onsite Conditions: Ditch and Front Slope Passed Inspection.

Figure D.5. Sample Unit No. 2 MUAV Captured Image: Failed To Capture Guard Rail.

Figure D.6. Sample Unit No. 2 Onsite Conditions: Guard Rail That Was Inspected.

Figure D.7. Sample Unit No. 3 MUAV Captured Image: Failed to Capture Culvert and Drain Pipe.

Figure D.8. Sample Unit No. 3 Onsite Conditions: Culvert and Drain Pipe That Was Inspected.

Figure D.9. Sample Unit No. 4 MUAV Captured Image: Ditch and Front Slope Failed Inspection.

Figure D.10. Sample Unit No. 4 Onsite Conditions: Ditch and Front Slope Passed Inspection.

Figure D.11. Sample Unit No. 5 MUAV Captured Image: Ditch and Front Slope Failed Inspection.

Figure D.12. Sample Unit No. 5 Onsite Conditions: Ditch and Front Slope Passed Inspection.

Figure D.13. Sample Unit No. 5 MUAV Captured Image: Failed to Capture Culvert and Drain Pipe.

Figure D.14. Sample Unit No. 5 Onsite Conditions: Culvert and Drain Pipe That Was Inspected.

Figure D.15. Sample Unit No. 6 MUAV Captured Image: Ditch and Front Slope Failed Inspection.

Figure D.16. Sample Unit No. 6 Onsite Conditions: Ditch and Front Slope Passed Inspection.

Figure D.17. Sample Unit No. 6 MUAV Captured Image: Failed to Capture Drain Inlet.

FigureD.18. Sample Unit No. 6 Onsite Conditions: Drain Inlet That Was Inspected.

Figure D.19. Sample Unit No. 6 Onsite Conditions: Drain Inlet That Was Inspected (Uncovered).

Figure D.20. Sample Unit No. 7 MUAV Captured Image: Ditch and Front Slope Failed Inspection.

Figure D.21. Sample Unit No. 7 Onsite Conditions: Ditch and Front Slope Passed Inspection.

Figure D.22. Sample Unit No. 7 MUAV Captured Image: Failed to Capture Guard Rail.

Figure D.23. Sample Unit No. 7 Onsite Conditions: Guard Rail That Was Inspected.

Figure D.24. Sample Unit No. 8 MUAV Captured Image: Ditch and Front Slope Failed Inspection.

Figure D.25. Sample Unit No. 8 Onsite Conditions: Ditch and Front Slope Passed Inspection.

Figure D.26. Sample Unit No. 10 MUAV Captured Image: Failed to Capture Culvert and Cross Drain Pipe.

Figure D.27. Sample Unit No. 10 Onsite Conditions: Culvert and Cross Drain Pipe That Was Inspected.

Figure D.28. Sample Unit No. 10 MUAV Captured Image: Failed to Capture Drain Inlet.

Figure D.29. Sample Unit No. 10 Onsite Conditions: Drain Inlet That Was Inspected.

Figure D.30. Sample Unit No. 10 Onsite Conditions: Drain Inlet That Was Inspected (Uncovered).

APPENDIX E

COLLEGE STATION, TX RIVERSIDE AIRFIELD DATA

Figure E.1 College Station, TX Riverside Airfield Experiment Location (Section denoted in Blue).

Table E.1. College Station, TX Riverside Airfield Reference Table.

Sample Unit No.	Size
1	2 by 10 Slabs (Approx. 5000 SF)
2	2 by 10 Slabs (Approx. 5000 SF)
3	2 by 10 Slabs (Approx. 5000 SF)
4	2 by 10 Slabs (Approx. 5000 SF)
5	2 by 10 Slabs (Approx. 5000 SF)
6	2 by 10 Slabs (Approx. 5000 SF)
7	2 by 10 Slabs (Approx. 5000 SF)
8	2 by 10 Slabs (Approx. 5000 SF)
9	2 by 10 Slabs (Approx. 5000 SF)
10	2 by 10 Slabs (Approx. 5000 SF)
11	2 by 10 Slabs (Approx. 5000 SF)
12	2 by 10 Slabs (Approx. 5000 SF)
13	2 by 10 Slabs (Approx. 5000 SF)
14	2 by 10 Slabs (Approx. 5000 SF)
15	2 by 10 Slabs (Approx. 5000 SF)

Table E.2. College Station, TX Riverside Airfield Sample Unit No. 1 Data.

Surveyor 1						MUAV						
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q	
14	L	11	55%	12	2	15	M	20	100%	28	3	
11	L	20	100%	5		14	M	20	100%	36		
5	H	1	5%	12		5	H	20	100%	12		
						2	L	6	30%	20		
m	**Min**					**m**	**Min**					
9	0.56					7	1.71					
Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	12	5	0.56				30	2	27	27	73
2	12	5	5	0.56				23	1	22		
MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	36	28	20	6	1.71			92	3	70	70	30
2	36	28	5	5	1.71			76	2	64		
3	36	5	5	5	1.71			53	1	53		

Table E.3. College Station, TX Riverside Airfield Sample Unit No. 2 Data.

Surveyor 1						MUAV						
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q	
14	L	2	10%	4	1	15	M	20	100%	28	4	
10	L	2	10%	2		14	M	20	100%	26		
5	H	20	100%	12		7	L	3	15%	8		
						5	H	20	100%	12		
m	**Min**					**m**	**Min**					
9	0.22					8	1.00					
Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	4	2	0.22				18	1	18	18	82
MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	28	26	12	8	1			75	4	54	55	45
2	28	26	12	5	1			72	3	54		
3	28	26	5	5	1			65	2	55		
4	28	5	5	5	1			44	1	44		

Table E.4. College Station, TX Riverside Airfield Sample Unit No. 3 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
14	M	1	5%	5	2	15	M	20	100%	28	3
14	L	5	25%	7		14	M	20	100%	36	
5	H	20	100%	12		5	H	20	100%	12	
m	**Min**					**m**	**Min**				
9	0.56					7	1.71				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	7	5	0.56				25	2	21	23	77
2	12	5	5	0.56				23	1	23		

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	36	28	12	1.71				78	3	59	61	39
2	36	28	5	1.71				71	2	61		
3	36	5	5	1.71				48	1	48		

Table E.5. College Station, TX Riverside Airfield Sample Unit No. 4 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
15	L	1	5%	2	1	15	M	20	100%	28	3
14	L	2	10%	4		14	M	20	100%	36	
10	L	1	5%	1		5	H	20	100%	12	
5	H	20	100%	12							
m	**Min**					**m**	**Min**				
9	0.11					7	1.71				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	4	2	1	0.11			19	1	19	19	81

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	36	28	12	1.71				78	3	59	61	39
2	36	28	5	1.71				71	2	61		
3	36	5	5	1.71				48	1	48		

Table E.6. College Station, TX Riverside Airfield Sample Unit No. 5 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
14	L	2	10%	4	3	15	M	10	50%	21	4
5	H	20	100%	12		14	M	10	50%	26	
3	M	1	5%	12		5	H	20	100%	12	
3	L	2	10%	15		3	L	6	30%	17	
m	**Min**					**m**	**Min**				
9	0.44					8	1.50				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	15	12	12	4	0.44			43	3	33	33	67
2	15	12	5	4	0.44			36	2	30		
3	15	5	5	4	0.44			29	1	28		

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	26	21	17	12	1.5			78	4	58	58	42
2	26	21	17	5	1.5			71	3	54		
3	26	21	5	5	1.5			59	2	51		
4	26	5	5	5	1.5			43	1	43		

Table E.7. College Station, TX Riverside Airfield Sample Unit No. 6 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
14	H	1	5%	14	4	15	M	20	100%	28	3
14	L	1	5%	2		14	H	20	100%	51	
13		1	5%	2		5	H	20	100%	12	
12	L	1	5%	10							
11	M	1	5%	9							
5	H	20	100%	12							
m	**Min**					**m**	**Min**				
9	0.22					6	2.00				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	14	12	10	9	2	0.22		47	4	35	35	65
2	14	12	10	5	2	0.22		43	3	34		
3	14	12	5	5	2	0.22		38	2	34		
4	14	5	5	5	2	0.22		31	1	33		

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	51	28	12	2				93	3	71	75	25
2	51	28	5	2				86	2	75		
3	51	5	5	2				63	1	63		

Table E.8. College Station, TX Riverside Airfield Sample Unit No. 7 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
15	L	3	15%	5	1	15	L	20	100%	15	3
14	M	1	5%	5		14	L	20	100%	14	
14	L	1	5%	2		8	L	1	5%	4	
5	H	1	5%	12		5	H	20	100%	12	
3	L	20	100%	5							
m	**Min**					**m**	**Min**				
9	0.22					9	0.44				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	5	5	5	2			29	1	29	29	71

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	15	14	12	4	0.44			45	3	34	34	66
2	15	14	5	4	0.44			38	2	32		
3	15	5	5	4	0.44			29	1	29		

Table E.9. College Station, TX Riverside Airfield Sample Unit No. 8 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
14	L	2	10%	4	1	15	L	20	100%	15	3
5	H	20	100%	12		14	L	20	100%	14	
						5	H	20	100%	12	
m	**Min**					**m**	**Min**				
9	0.44					9	1.33				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	4	0.44					16	1	16	16	84

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	15	14	12	1.33				42	3	32	32	68
2	15	14	5	1.33				35	2	29		
3	15	5	5	1.33				26	1	26		

Table E.10. College Station, TX Riverside Airfield Sample Unit No. 9 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
5	L	1	5%	3	1	15	M	20	100%	28	3
4	H	20	100%	12		14	M	20	100%	36	
						5	H	20	100%	12	
m	**Min**					**m**	**Min**				
9	0.33					7	1.71				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	3	0.33					15	1	15	15	85

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	36	28	12	1.71				78	3	59	61	39
2	36	28	5	1.71				71	2	61		
3	36	5	5	1.71				48	1	48		

Table E.11. College Station, TX Riverside Airfield Sample Unit No. 10 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
15	L	1	5%	2	1	15	L	20	100%	15	3
14	L	2	10%	4		14	L	20	100%	14	
5	H	20	100%	12		5	H	20	100%	12	
m	**Min**					**m**	**Min**				
9	0.22					9	1.33				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	4	2	0.22				18	1	18	18	82

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	15	14	12	1.33				42	3	32	32	68
2	15	14	5	1.33				35	2	29		
3	15	5	5	1.33				26	1	26		

Table E.12. College Station, TX Riverside Airfield Sample Unit No. 11 Data.

Surveyor 1						MUAV						
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q	
14	L	1	5%	2	1	15	L	20	100%	15	4	
13		1	5%	1		14	L	20	100%	14		
5	H	20	100%	12		6	L	5	25%	1		
3	L	1	5%	5		5	H	20	100%	12		
m	**Min**					**m**	**Min**					
9	0.11					9	0.11					
Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	5	2	1	0.11			20	1	20	20	80
MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	19	15	14	12	1			61	4	43	43	57
2	19	15	14	5	1			54	3	42		
3	19	15	5	5	1			45	2	38		
4	19	5	5	5	1			35	1	35		

Table E.13. College Station, TX Riverside Airfield Sample Unit No. 12 Data.

Surveyor 1						MUAV						
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q	
14	L	3	15%	5	2	15	M	20	100%	28	4	
5	H	20	100%	12		14	M	20	100%	36		
3	L	2	10%	8		5	H	20	100%	12		
						3	L	2	10%	8		
m	**Min**					**m**	**Min**					
9	0.56					7	1.14					
Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	8	5	0.56				26	2	22	23	77
2	12	5	5	0.56				23	1	23		
MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	36	28	12	8	1.14			85	4	60	65	35
2	36	28	12	5	1.14			82	3	62		
3	36	28	5	5	1.14			75	2	65		
4	36	5	5	5	1.14			52	1	52		

Table E.14. College Station, TX Riverside Airfield Sample Unit No. 13 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
15	L	1	5%	2	2	15	L	20	100%	15	3
14	H	1	5%	13		14	L	20	100%	14	
14	L	2	10%	4		5	H	20	100%	12	
5	H	20	100%	12							
m	**Min**					**m**	**Min**				
9	0.22					9	1.33				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	13	12	4	2	0.22			31	2	26	26	74
2	13	5	4	2	0.22			24	1	24		

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	15	14	12	1.33				42	3	32	32	68
2	15	14	5	1.33				35	2	29		
3	15	5	5	1.33				26	1	26		

Table E.15. College Station, TX Riverside Airfield Sample Unit No. 14 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
15	L	1	5%	2	2	15	L	20	100%	15	4
14	L	1	5%	2		14	L	20	100%	14	
5	H	20	100%	12		5	H	20	100%	12	
4	M	1	5%	12		2	M	3	15%	20	
m	**Min**					**m**	**Min**				
9	0.22					9	1.33				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	12	12	2	2	0.22			28	2	24	24	76
2	12	5	2	2	0.22			21	1	21		

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	20	15	14	12	1.33			62	4	44	44	56
2	20	15	14	5	1.33			55	3	42		
3	20	15	5	5	1.33			46	2	39		
4	20	5	5	5	1.33			36	1	36		

Table E.16. College Station, TX Riverside Airfield Sample Unit No. 15 Data.

Surveyor 1						MUAV					
Distress Type	Severity	No. of Slabs	Density	DV	q	Distress Type	Severity	No. of Slabs	Density	DV	q
15	L	1	5%	2	3	15	M	20	100%	28	4
14	L	1	5%	2		14	M	20	100%	36	
13		1	5%	1		5	H	20	100%	12	
9		3	15%	14		3	L	6	30%	17	
5	H	20	100%	12							
3	L	6	30%	17							
m	**Min**					**m**	**Min**				
9	0.11					7	1.71				

Surveyor 1												
No.	DV							Total	q	CDV	Max CDV	PCI
1	17	14	12	2	2	0.11		47	3	37	37	63
2	17	14	5	2	2	0.11		40	2	35		
3	17	5	5	2	2	0.11		31	1	32		

MUAV												
No.	DV							Total	q	CDV	Max CDV	PCI
1	36	28	17	12	1.71			95	4	68	78	22
2	36	28	17	5	1.71			88	3	78		
3	36	28	5	5	1.71			76	2	72		

Table E.17. Summary Table of College Station, TX Riverside Airfield PCI Ratings

Sample Unit No.	Surveyor 1	MUAV
1	73	30
2	82	45
3	77	39
4	81	39
5	67	42
6	65	25
7	71	66
8	84	68
9	85	39
10	82	68
11	80	57
12	77	35
13	74	68
14	76	56
15	63	22

VITA

Name: William Scott Hart

Address: Department of Civil Engineering
c/o Dr. Nasir Gharaibeh
Texas A&M University
College Station, TX 77843-3136

Email Address: ScottHart09@gmail.com

Education:

B.S., Civil Engineering, Texas A&M University, 2009
M.S., Civil Engineering, Materials Engineering, Texas A&M University, 2010

Current Research:

- Improving the inspection process for Roadside Condition Surveys